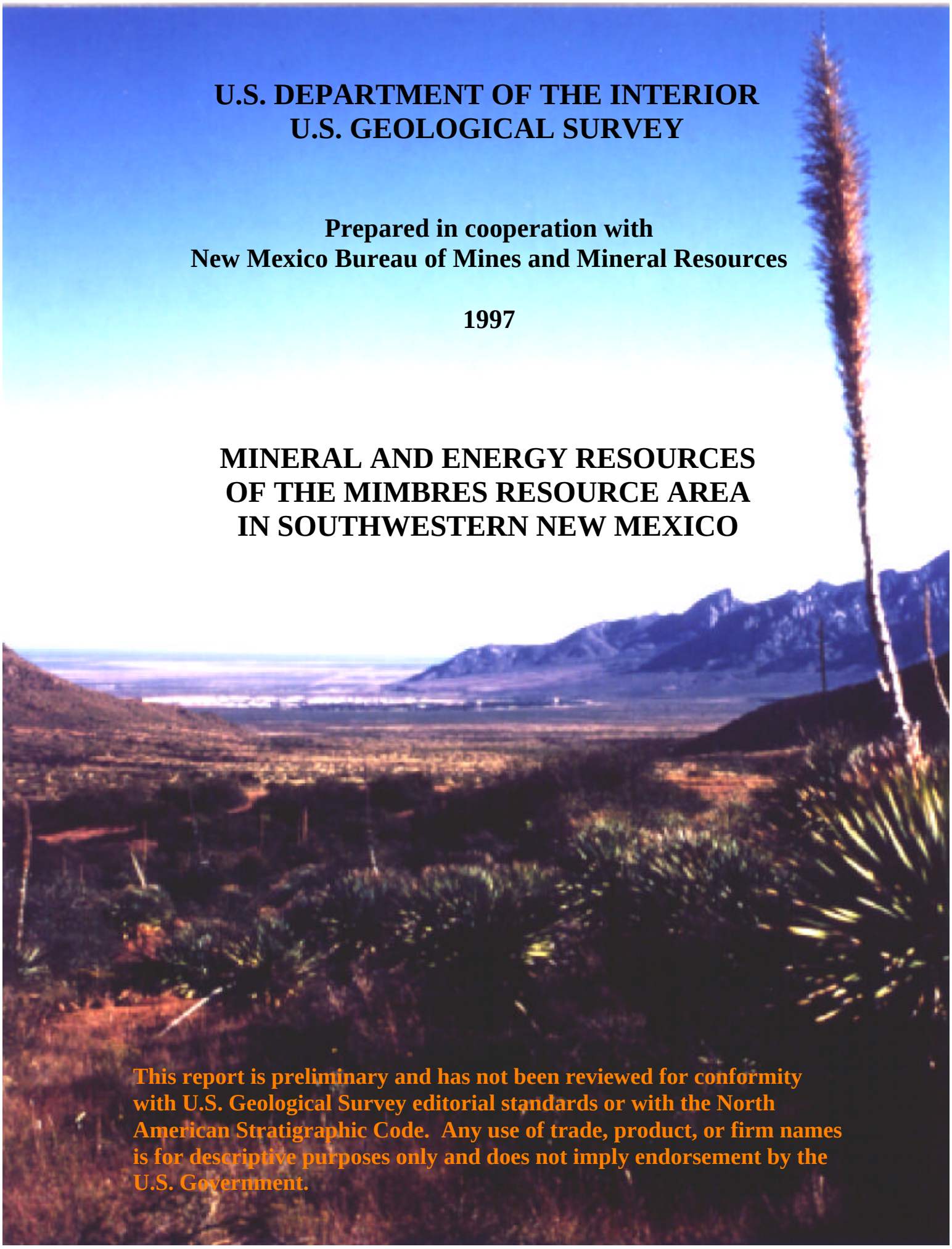


U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Prepared in cooperation with
New Mexico Bureau of Mines and Mineral Resources

1997

MINERAL AND ENERGY RESOURCES OF THE MIMBRES RESOURCE AREA IN SOUTHWESTERN NEW MEXICO

This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards or with the North American Stratigraphic Code. Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Cover: View looking south to the east side of the northeastern Organ Mountains near Augustin Pass, White Sands Missile Range, New Mexico. Town of White Sands in distance. (Photo by Susan Bartsch-Winkler, 1995.)

MINERAL AND ENERGY RESOURCES OF THE MIMBRES RESOURCE AREA IN SOUTHWESTERN NEW MEXICO

By SUSAN BARTSCH-WINKLER, Editor

U. S GEOLOGICAL SURVEY OPEN-FILE REPORT 97-521

U.S. Geological Survey

Prepared in cooperation with
New Mexico Bureau of Mines
and Mineral Resources, Socorro

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
Mark Shaefer, Interim Director

For sale by U.S. Geological Survey, Information Service Center
Box 25286, Federal Center
Denver, CO 80225

Any use of trade, product, or firm names in this publication is for descriptive purposes only
and does not imply endorsement by the U.S. Government

MINERAL AND ENERGY RESOURCES OF THE MIMBRES RESOURCE AREA IN SOUTHWESTERN NEW MEXICO

Susan Bartsch-Winkler, Editor

Summary

Mimbres Resource Area is within the Basin and Range physiographic province of southwestern New Mexico that includes generally north- to northwest-trending mountain ranges composed of uplifted, faulted, and intruded strata ranging in age from Precambrian to Recent. Rocks within the province have significant mineral deposits, many associated with tectonic structures related to Basin and Range development, within 63 mining districts.

This report includes a compilation of all known metallic and industrial mineral deposits and occurrences within Grant, Hidalgo, Luna, and Doña Ana Counties in southwestern New Mexico and historical data on their production. The known deposits are described by 25 mineral deposit models and an assessment of the potential for unknown deposits within one kilometer of the surface for each model type is included. Industrial mineral and energy resources are recognized, along with an assessment of sand and gravel and crushed rock resources using new and innovative techniques. Also described in this report are (1) a compilation of the geology of each mountain range; (2) a description of geological events that took place throughout geologic time; (3) a geophysical analysis; (4) descriptions of resource assessment techniques; (4) a complete reference list; and (5) a compilation of stratigraphic unit names. ARC/INFO files used in making resource assessments are separate files on the CD-ROM.

The Mimbres Resource Area includes the most mineralized area in New Mexico and the highest metallic mineral production in the State. Total production from the study area is estimated to include 15.7 billion lbs of copper, 100 million oz of silver, 1.2 million oz of gold, 651 million lbs of lead, and 2.8 billion lbs of zinc, and accounts for more than 90 percent of the total copper, zinc, and silver production from New Mexico from 1848 until 1993. Production from the area has also amounted to 89 percent of the lead and 46 percent of the gold in New Mexico. Currently, metal mining operations are in the Silver City area (Chino, Tyrone, and Continental mines), and in the Lordsburg and Steeple Rock districts.

Twenty-five deposit types occur within the study area. Worldwide statistics on these deposit types were used in conjunction with other geological characteristics to determine the probability of undiscovered deposits of these types in the Mimbres Resource

Area. Results of the mineral resource assessment indicate a 90 percent probability for expected mean tonnages of 200 tonnes Au, 11,000 tonnes Ag, 9.4 million tonnes Cu, 9.1 million tonnes Fe, 450,000 tonnes Mn, 300,000 tonnes Mo, 470,000 tonnes Pb, 85 tonnes WO_3, and 600,000 tonnes Zn that are contained in an estimated total 2.5 billion tonnes of mineralized material. There are 9 chances out of 10 that the study area will contain these or greater tonnages. Gross in-place values (GIPV) of expected tonnages show that copper has the highest value, with approximately $77 billion or 63 percent of the mean GIPV of all of the metals deposits in the study area. Iron in skarn deposits has the next highest value, with approximately $15 billion or 12 percent of the total GIPV, and molybdenum in porphyry deposits is the third highest, with approximately $13 billion or 10 percent of the total GIPV. By far the highest GIPV for any deposit type present is porphyry copper-molybdenum deposits, with an estimated total of $89 billion in gold, silver, copper, lead, zinc, and molybdenum.

The single favorable area with the highest GIPV is the Peloncillo area in the Mogollon-Datil volcanic field, which was assessed for porphyry deposits. This area has an expected mean GIPV of $21 billion (over 17 percent of the total). Aggregated multiple favorable areas indicate that the Piños Altos-Santa Rita area has the greatest GIPV ($24 billion), and the Peloncillo Mountains contains the second greatest GIPV ($22 billion).

Industrial mineral commodities are overshadowed in importance by the metallic minerals, but they are nonetheless highly varied and may be of significance as the area increases in population. Known deposits or occurrences of aggregate, alum, caliche, clay, dimension stone, travertine, calcite, talc, fluorspar and barite, gemstones and collectible minerals, guano, gypsum, iron, jarosite, manganese, marble, perlite, ricolite, scoria and pumice, and zeolite are present in the area. Geothermal resources, currently utilized in a small way, may be of greater importance in the future in southwest New Mexico. Coal and oil and gas resources are currently only of limited importance in the study area.

INTRODUCTION

The sparsely vegetated Mimbres Resource Area encompasses about 14,198 mi^2 (36,773 km^2; 9,086,720 acres), including the counties of Grant, Hidalgo, Luna, and Doña Ana, in southwestern New Mexico. Of the total, the U.S. Bureau of Land Management (BLM) manages about 14,000 sq mi (36,260 km^2; 9 million acres) on the surface and about 11,000 sq mi (28,490 km^2; 7.5 million acres) in the subsurface (**table 1-1**; **figure 1-1**). The study area is within the "Colorado Plateau semi-desert province" and the "Arizona-New Mexico mountains semi-desert-open woodland-coniferous forest-alpine meadow province" ecoregions of the United States (Bailey, 1994). High plains regions in the Mimbres Resource Area range in altitude from about 1068m to 1373m; mountainous regions attain altitudes of about 2745m . Numerous national forests, wilderness areas, refuges, ranges and facilities, monuments, and State parks lie within the Mimbres Resource Area boundaries (**figure 1-2**). The largest cities within the resource area boundary include Las Cruces, Deming, Lordsburg, and Silver City.

Federal wilderness lands [Wilderness Study Areas (WSA) and Instant Study Areas (ISA)] include:

Aden Lava Flow WSA
Alamo-Hueco Mountains WSA
Big Hatchet Mountains WSA
Blue Creek WSA
Cedar Mountains WSA
Cookes Range WSA
Cowboy Springs WSA
Florida Mountains WSA
Gila WSA
Guadalupe Canyon ISA
Las Uvas Mountains WSA
Organ Mountains WSA
Redrock WSA
Robledo Mountains WSA
West Portrillo Mountains WSA

National Forest (NF) lands include:

Coronado NF
Gila NF

Other Federal lands include:

Fort Bliss Military Reservation
NASA Test Facility
San Andres National Wildlife Refuge (NWR)
White Sands National Monument (NM)
White Sands Missile Range (WSMR)

New Mexico State Parks (SP) include:

City of Rocks SP
Leasburg Dam SP
Pancho Villa SP
Rockhound SP

The western boundary of the study area is the New Mexico-Arizona state line, the southern boundary is the border with Mexico, and the southeastern tip borders the state of Texas.

The populous Rio Grande valley in southern Doña Ana County and isolated parts of valleys in Hidalgo and Luna Counties irrigated by wells are less typical than the sparsely settled, arid to semiarid regions that are used primarily for ranching and that comprise most of the rest of the study area.

PURPOSE AND METHODOLOGY

As the Nation's principal conservation agency, the Department of the Interior has responsibility for the country's public lands and natural resources. As part of that responsibility, the Department assesses the mineral and energy resources and works to assure that their development (or non-development) is in the best interest of the country. Throughout its history, the U.S. Geological Survey (USGS), an agency of the Department of the Interior, has acquired mineral-resource information on the public lands and provided assessments to agencies such as the Bureau of Land Management (BLM) and the U.S. Forest Service (USFS), who are caretakers and managers of public lands and have jurisdiction over surface and subsurface mineral rights. Initially, mineral deposit models for quantitative mineral-resource assessments were necessarily derived when the 1964 Wilderness Act required that mineral values of Wilderness lands be determined, as a precaution against the day when a national emergency might make their mining necessary (Ovenshine, 1986). Quantitative mineral-resource assessments and analyses of mineral resources now provide important data for land-use decisions affecting national and regional resource planning.

Mimbres Resource Area (the "study area" of this report) contains important metals and nonmetals, industrial commodities, and energy resources in many geologic settings. Additional

undiscovered resources are likely in the resource area. The primary purpose of this report is to synthesize known information on the geology, geophysics, geochemistry, mining history, and district occurrences, and use this information in making an assessment of certain mineral resources This report includes discussions and descriptions of the geological, geochemical, geophysical, stratigraphic, and tectonic settings, a description of the mineral and energy resource occurrences, an historical account of their exploration and production, a description of mineral deposit models, and a description and analysis of mineral resource tracts that are likely to contain as yet undiscovered resources. Both cited and uncited references (**Appendix A**), and stratigraphic units mentioned in this document (**Appendix B**) are included. This report, though intended for use by the BLM, is a comprehensive description and compilation of the geological features in the study area and can also be used as a reference document by other interested parties.

Quantitative assessment of certain resources were done using the MARK-III computer program for mineral-resource simulation (Drew and others, 1986; Root and Scott, 1988; Root and others, 1992), a statistical method that is used herein to estimate potential gross in-place tonnages for undiscovered resource commodities. The mineral-resource assessment of the Mimbres Resource Area relies upon previous work of the U.S. Geological Survey, the Canadian Geological Survey, and others who have developed mineral deposit models.

This report is the result of an interdisciplinary and interagency study by the USGS, the New Mexico Bureau of Mines and Mineral Resources (NMBMMR), and BLM, by interagency agreement between the BLM and the USGS. Limited field investigations of the Mimbres Resource Area were independently conducted in 1993-1994 by Susan Bartsch-Winkler, Jerry R. Hassemer, Douglas P. Klein, Sherman P. Marsh, E.L. Mosier, James A. Pitkin, J. David Sanchez, M.L. Silberman, David M. Sutphin, and Alan R. Wallace, all of USGS, and Virginia T. McLemore, NMBMMR. Earlier fieldwork and laboratory data is included in sections on geothermal resources by Wendell A. Duffield and Susan S. Priest (USGS), aeromagnetic and gravity surveys by Gerda A. Abrams (USGS), perlite by James M. Barker (NMBMMR) and Ernest F. Scharkan (Dennis Engineering Co., Socorro), and zeolites by Richard A. Sheppard (USGS). A new assessment technique for aggregate resources is described and used by William H. Langer and others (USGS). A summary of all available previously published geologic reports and maps on surface and subsurface geology, mineral production, and occurrences was prepared by Bartsch-Winkler, McLemore, and Sutphin. Information from the Anaconda Collection (University of Wyoming, Laramie), and the NMBMMR on known mineral deposits was examined by McLemore and Bartsch-Winkler. Silberman contributed information on the geology of the McGhee Peak mining district and the Peloncillo Mountains, and to the assessment. Geochemical data compiled by

Hassemer and Marsh from new field studies, internal files of the USGS, published data, and from the National Uranium Resource Evaluation (NURE) surveys were used by team members in their assessment of mineral resources. The geologic map was compiled and initially prepared as a GSMap digital file by Orin J. Anderson and G.E. Jones, NMBMMR. Gregory N. Green (USGS) prepared the ARC/INFO files for release. These files consist of .e00 files, AML's, and other ancillary files in the directory *arc_files*. This directory is accessible only by computer systems complying with the ISO 9660 standard, such as UNIX and MS-DOS/Microsoft Windows systems, but not MacOS systems. View the file, *a_read.me* in the *arc_files* directory for more information.

This document was edited from initial drafts, some incomplete, received just prior to a personnel reduction by the U.S. Geological Survey in September 1995. Bartsch-Winkler, coordinator of the study team, subsequently compiled and edited the final report in the capacity of a USGS Scientist Emeritus from these manuscripts without the benefit of consultation with some authors. Ronald R. Tidball, USGS Scientist Emeritus, assisted in computer manipulations needed for digital publication.

ACKNOWLEDGMENTS

This report was compiled from many sources, including numerous journal articles, guidebooks, dissertations, and theses that are not individually referenced in the text. All of the references utilized, published and unpublished, are included in the bibliography (**Appendix A**). For the sake of readability, only some of the major or most recent references are cited. Nevertheless, we acknowledge all references in the bibliography for their contribution to this compilation.

We thank Charles O'Donnell, Geologist, BLM Las Cruces District Office, who organized and participated in field conferences, facilitated field operations, and offered advice on content of the report. We are indebted to Dr. Charles Chapin, Director and State Geologist, New Mexico Bureau of Mines and Mineral Resources, Socorro, who encouraged personnel from the Bureau to participate in the project. Personnel at the White Sands Missile Range assisted us in our reconnaissance examination of areas within the study area. Phelps-Dodge Corporation and Cobre Mining Company gave various members of the study team access to their properties. We are especially grateful to the numerous reviewers, text and map editors, stratigraphic-names editors, and others who assisted in the compilation of data, reviews, and provided helpful advice,

suggestions, and guidance. We especially thank David A. Lindsey, USGS, who made many helpful suggestions to the first draft. Other reviewers from the USGS include Warren Finch, Hans D. Ackermann, Leroy W. Pankratz, Charles H. Thorman, and James C. Ratté. Reviewers from the NMBMMR include Robert Eveleth, Frank Kottlowski, and Virgil Lueth. Robert North and many students at New Mexico Institute of Mining and Technology assisted in compiling the mineral production statistics over many years. Daniel Hack, NMBMMR, provided technical assistance to McLemore. Seismic refraction processing, including construction of the velocity sections, was accomplished by Ackermann, Pankratz, and Danny A. Dansereau (USGS) with funding provided through David W. Wilkins of Water Resources Division (WRD), USGS, Albuquerque, N. Mex. Charles E. Heywood (WRD, Albuquerque) and McLemore were helpful in providing sources of drill-hole information for the area. Heywood also provided new gravity data. Jackie M. Williams (USGS) assisted in data processing and in the initial graphical work on the velocity sections. James D. Hoffman, USGS, assisted in final production of the CD-ROM. Margaret A. Clemensen, USGS, assisted in manuscript preparation. David McCraw, NMBMMR, drafted the illustrations for McLemore. Finally, Gary R. Winkler provided encouragement and suggested completion of this report.

SUMMARY OF THE GEOLOGY OF SOUTHWESTERN NEW MEXICO

by Susan Bartsch-Winkler

GEOLOGIC SETTING

The largest part of the resource area is within the Basin and Range physiographic province of mountain range horsts and intervening valley grabens. The geologically complex mountain ranges of the area are composed of basement Precambrian rocks, Paleozoic and Mesozoic bedded rocks, and intrusive and volcanic rocks (**Plate 1**, **figure 1-3)**. The ranges have been uplifted and faulted repeatedly. Most ranges are linear, generally north- to northwest-trending and are separated by valleys filled with river, terrace, alluvial fan, and playa deposits.

The Mogollon-Datil volcanic field, mainly in Grant and Hidalgo Counties, is a high plateau consisting of thick volcanic ash-flow sheets, remnants of volcanoes, and plutonic rocks; it is covered by 2-3 km of Eocene and Oligocene volcanic ash flows The Mogollon-Datil volcanic field separates the Colorado Plateau physiographic province on the north from the Basin and Range physiographic province to the south (in the Mimbres Resource Area). The northwest-trending transition zone (the Texas lineament extension), marked by the Mogollon Arch, Mimbres and Mangas trenches, and the Burro uplift, crosses the study area. Large mining districts occur along the northeast-trending Santa Rita and Morenci lineaments. Major porphyry copper deposits are mined in southwestern New Mexico, and date mainly from the Laramide orogeny (see McLemore and others, and McLemore and Sutphin, this volume).

Burro Mountains uplift (Drewes, 1989), a Precambrian or Paleozoic uplift underlain by Precambrian basement rocks, is the largest outcropping of Precambrian rocks in southwestern New Mexico. South of the Burro Uplift, the mountain ranges and valleys have north-south trends, indicating structures of the Basin-and-Range province.

The eastern part of the resource area is traversed by the Rio Grande Rift (Chapin, 1975), a zone of crustal fractures resulting from extension of the Earth's crust during late Tertiary to Recent time. The area affected by the Rift consists of widely separated, tilted, mountain horsts and grabens. Broad pediments and fans extend from the Rift mountains to the Rio Grande; north-trending linear fault systems and terraced cliffs occur along the Rio Grande valley. Many of the Rift features are superimposed on structures formed during Mesozoic and Paleozoic times. Conspicuous landforms formed by rifting and from associated volcanism are as young as 10 m.y. old. Young volcanic features include lava flows, craters, and cinder cones.

The boundary of the Rio Grande Rift in south-central New Mexico is more poorly defined than it is in northern and central New Mexico. Within the Mimbres Resource Area, the Rift merges

with the Basin and Range province. In this part of New Mexico, the Rift may be more deeply buried by Quaternary sediments and basalt than it is further to the north, and is presently less active than it was prior to 5 m.y. ago.

HISTORICAL GEOLOGY AND TECTONISM IN THE MIMBRES RESOURCE AREA—STRUCTURES RELATING TO TECTONIC EVENTS

An understanding of the history of structural development of the region is key to conclusions on the occurrence and formation of mineral and energy resources throughout the study area. Within the boundaries of the Mimbres Resource Area, mineralization took place episodically during tectonic events that spanned Precambrian through late Tertiary and Quaternary time. Much of the rock alteration and mineralization occurred along reactivated faults, related structures, and within or adjacent to volcanic and plutonic edifices. The study area includes the largest mining districts having the largest production in New Mexico. Much of the structural history of the study area described below is from Dickinson (1989).

Precambrian (Proterozoic) Events

In southwest and south-central New Mexico, Proterozoic metamorphic rocks of greenschist grade (Ernst, 1991) are intruded by granite and form the cores of the Little and Big Burro Mountains, Florida Mountains, Big Hatchet Mountains; San Diego Mountain, and the San Andres, Organ, Franklin, and Cookes ranges (**figure 1-3** and **figure 1-4**) (Condie, 1981). The rocks were formed during Proterozoic crustal consolidation of the southwestern North American craton (Dickinson, 1989). Exposed Proterozoic rocks are generally north-northeast- to northwest-trending; they range in age from 1.7 b.y. (billion years before present) to 1.3 b.y.

Lineaments

Lineaments are linear zones highlighted by topographic and geologic features. In many cases, they represent basement faults (Precambrian), but in other cases their formation and origins may be unclear. Lineaments have been described within and adjacent to the study area.

Texas lineament and lineament zone

The northwest-trending Texas lineament, a major strike-slip fault zone in west Texas, terminates at El Paso (Hill, 1902; Ransome, 1915). Hypothetically, the lineament may extend northwest beneath the study area, and may even connect to the northwest-trending Walker Lane lineament near Las Vegas, Nev. (Kelley, 1955; Drewes, 1989a). Both the Texas lineament and the Walker Lane linement are thought to have had right-lateral offset. In the study area, the lineament zone is defined by alignment of basins and ranges, faults, and mining districts (**figure 1-4**) (Drewes, 1991; McLemore, 1994). Within the lineament zone of the study area, faults are typically dip-slip faults (normal, reverse, and thrust faults); strike-slip movement (involving lateral movement and offset) is less well documented, but present locally (Turner, 1962;

Wertz, 1970a,b; Muehlberger, 1980; Seager, 1983).

The lineament and associated structures may define a structural discontinuity between the rigid Proterozoic craton of North America and younger marine sedimentary rock deposited along the margin of the craton. The discontinuity may represent an ancient active continental plate margin along which multiple orogenies took place. For example, during the Late Paleozoic Marathon orogeny, a thick pile of sedimentary rocks were accreted northward onto the edge of the craton (along the locus of the Texas lineament zone in Texas) and deformed.

The Texas lineament zone may be a series of aligned faults that were initiated in Precambrian time and have had repeated subsequent movement and reactivation. One of the most important of these tectonic events in the study area, the late Mesozoic and early Tertiary Laramide orogeny, apparently was focused along the projection of the Texas lineament zone.

Morenci and Santa Rita (New Mexico Mineral Belt) lineament zones

The Morenci and Santa Rita lineaments are northeast-trending features that are located in the western and northern parts of the study area (McIntosh and others, 1990 a,b; Chapin and others, 1978) (**figure 1-4**). The Santa Rita lineament is not well documented, but is distinguished mainly by the zone of porphyry copper deposits (Cananea, Bisbee, Santa Rita, and Tyrone), by smaller epithermal districts along its trend (Lowell, 1974), and by Laramide intrusions and northeast-trending faults (Rose and Baltosser, 1966; McLemore, 1994). The Santa Rita lineament extends from Cananea, Sonora, Mexico, to Santa Rita, N. Mex. The Morenci lineament, which crosses the northwestern corner of the study area, includes the Safford and Morenci porphyry copper deposits (Arizona), the Morenci uplift (Cather and Johnson, 1986), and the silver-gold deposits of the Mogollon district (Lowell, 1974; Chapin and others, 1978). These two lineaments are probably younger than the Texas lineament zone because their locations are based on Laramide-age features.

Deposition in Paleozoic and Early Mesozoic Time

In southern New Mexico, Precambrian rocks are unconformably overlain by Paleozoic (Cambrian through Permian) rocks (**figure 1-3**). Most of the mountain ranges in the study area expose Paleozoic rocks. Paleozoic rocks contain evidence for the opening of the proto-Atlantic ocean in the Gulf of Mexico region in late Precambrian and early Paleozoic time (Thomas, 1977, 1978; Salvador, 1991) and accompanying draping of marine sediments along the southern strandline of the North American craton. Episodes of folding and faulting, evidenced by regional and local Paleozoic unconformities in the stratigraphic section, formed basins and uplifts. In southern New Mexico, unconformities occur mainly in Middle Ordovician, Early Silurian, and Late Silurian to Middle Devonian rocks (Seager, 1983). Within the study area, Paleozoic

formations on the seaward (southern) side of the craton are thousands of meters thick. Thickness of the Paleozoic formations total as much as 4,118m in the southwestern part of the study area and about 2,500m thick near El Paso, but thin to about 1,007m north of the study area (Kottlowski, 1963; Greenwood and others, 1977; Thompson, 1982).

In late Paleozoic and early Mesozoic time, the western and southeastern margins of the North American continent underwent tectonism—the Antler (Devonian-Mississippian) and Sonoma (Permian-Triassic) orogenies in the west (mainly in California and Nevada) and the middle to upper Pennsylvanian Ouachita orogeny in Oklahoma and the mainly Permian (Wolfcampian) Marathon orogeny in Texas in the southeastern part of the craton. The upper part of the Paleozoic section records rapid, thick sedimentation and increased tectonism that is thought to represent the closing of the proto-Atlantic and collision and welding of the North American plate with the African and South American plates to form the supercontinent called Pangaea (Salvador, 1991). During these episodes, considerable thicknesses of oceanic rocks and sediment with sources to the south and southeast were tectonically transported north- to northwestward and stacked onto the North American continent (Dickinson, 1989). These imbricated slices of oceanic rocks are now present mainly in the southern half of the Mimbres Resource Area. Events that took place along the Cordilleran margin to the west in present-day California probably did not affect the deposition in the study area during Paleozoic time.

The northwest-directed collision of Pangaea with North America along the Ouachita and Marathon foldbelts in Texas and Mexico produced north- to northwest-directed structures along the margin of the North American craton in Pennsylvanian and Permian time. Within the craton, complex stresses resulted in formation of basins and uplifts with diverse orientations (Ross and Ross, 1986). The Burro uplift in Grant County, the Florida Island uplift in the Florida Mountains of Luna County, the Orogrande basin in eastern Doña Ana County and Otero County, and the Pedregosa basin mostly in southern Hidalgo County and Mexico, were formed by stresses that were projected into the craton during Pennsylvanian and Permian time (Kluth and Coney, 1981) (**figure 1-4**). Other features near the study area that were formed by late Paleozoic tectonism include the Defiance-Zuni uplift in northwestern New Mexico, southeastern Utah, and northeastern Arizona; the Pedernal uplift in the Sacramento Mountains of western Lincoln County and northern Otero County, New Mexico; and the Delaware Basin in southeastern New Mexico and Texas.

The Florida Island (Mountains), Burro, and the Pedernal uplifts formed islands surrounded by Pennsylvanian seas (Kottlowski, 1962). The Orogrande basin received sediment from the Defiance-Zuni and Pedernal uplifts. Most of the deposition in adjoining basins took place in Pennsylvanian time; however, the first sediments deposited into the Orogrande Basin were Upper

Mississippian in age, including parts of the the Lake Valley Formation (**figure 1-3**; **Appendix B**). The Orogrande basin persisted into Late Permian time. As much as 1,220m of Pennsylvanian rocks near the northern San Andres Mountains north of the study area fill the Orogrande basin (Greenwood and others, 1977). Northwest-trending Pedregosa Basin also formed initially in Mississippian time, although most of the deposition took place in Pennsylvanian time. An estimated 3,050m was eroded from the Burro and Florida Islands uplifts and accumulated in the Pedregosa Basin; 1,525m of sediments were deposited in Orogrande Basin (Ryder, 1983; Seager, 1983), generally thinning to the north, west, and east. Limestone and dolomite reefs of Late Permian age indicate shallow seas (final infilling of the Pedregosa basin) in the area of the Big Hatchet Mountains. However, much of the middle and late Permian sedimentary record is missing from the study area.

In Mesozoic time, southwestern New Mexico was little affected by tectonism and was marked by a long period of continental sedimentation (fluvial redbed, strandline, and eolian deposits) in the region of the Colorado Plateau of Utah, southern Colorado, northern Arizona, and northwestern New Mexico (north of the study area). In southern and southwestern New Mexico, exposures of Triassic or Jurassic sedimentary or igneous rocks are absent. The southwestern part of New Mexico was probably part of the broad highland that provided a source for the continental sediments of Mesozoic age on the Colorado Plateau.

In late Mesozoic time, two types of basins (one formed during crustal compression and the other during crustal extension) developed contemporaneously with arc magmatism and tectonism in the Sierra Nevada and Baja California. In northern New Mexico and Arizona, a foreland depositional basin formed mainly in late Cretaceous time by downbowing of the crust during compressional, west-directed thrusting mainly in middle Cretaceous time in the Sevier orogenic belt in Nevada and Utah. In southern Arizona, southern New Mexico, northern Mexico, and Texas, fault-bounded grabens or troughs (aulacogens) formed mainly in early Cretaceous time by crustal extension east of the Sierra Nevada magmatic arc as sea-floor spreading began in the Gulf of California in Jurassic time (Dickinson, 1989). The Burro uplift–Deming axis (Elston, 1958; Turner, 1962) projected northwestward through the Florida and Burro Mountains from the West Potrillo Mountains. Although the uplift was probably initiated in Mississippian time, the deposits that were laid down after formation of the structure show its effects; for example, deflection of the strike of bedding to align with the northwest-trending structure, and disparities in unit thicknesses on either side of the uplift (Turner, 1962). The uplift separated thick sections of Lower Cretaceous marine and nonmarine rocks (the Bisbee Group) south of the uplift from thin and discontinuous sections of these rocks north of the uplift (Zeller, 1965, 1970; Hayes, 1970; Seager, 1983). South

of the uplift, Upper Cretaceous and Lower Tertiary rocks are very thick (more than 4,000m thick); north of the uplift, Upper Cretaceous rocks are preserved only in Laramide basins (Kelley and Silver, 1952).

Aulacogens include the Bisbee Basin in southwestern New Mexico and southeastern Arizona, and the Chihuahua Trough in northern Mexico (Dickinson, 1989); the Bisbee basin was superimposed on the earlier-formed Pedregosa basin within the study area. Lower Cretaceous rocks of the Bisbee Group, are as thick as 4,575m (Hayes, 1970; Kottlowski, 1971; Greenwood and others, 1977; Ryder, 1983). The abrupt southwestern edge of the Mogollon Highlands is interpreted to be the rifted edge of the Bisbee Basin (Dickinson, 1989). [Evidence for the Mogollon Highlands in central Arizona and west-central New Mexico is in the regional unconformity at the base of the Upper Cretaceous Dakota Sandstone, and progressive onlap to the southwest of older Cretaceous units beneath the unconformity (Dickinson, 1989); lower Cretaceous units thin or are not present over the Burro Uplift and areas to the north.] Lower Cretaceous rocks are regionally unconformable on underlying units throughout southwestern New Mexico, southeastern Arizona, western Texas, and adjacent parts of northern Mexico, with their coarse-grained deposits marking the site of initial rift basin margins. In southwestern New Mexico, thick deposits of Early Cretaceous clastic sediments as occur in the Big Hatchet Mountains, Little Hatchet Mountains, and Sierra Rica, were presumably eroded from the Burro and Florida Mountains uplifts and deposited in the Bisbee basin

Cretaceous rocks are present north of the Bear Peak fold and thrust zone on the northeastern edge of the study area in the San Andres Mountains, and probably are source rocks for Tertiary deposits in the southern San Andres Mountains, Organ Mountains, Bishop Cap, and northern Franklin Mountains (Seager, 1981).

Laramide Orogenic Events and Structures (Late Cretaceous to Middle Eocene)

Within the North American continental plate, compressional stresses caused thickening of crustal material as the plate overrode the eastward-verging Pacific oceanic plate. The oceanic (downgoing) plate may have had a markedly lesser dip in Late Cretaceous and early Tertiary time than it did earlier in Cretaceous time (Coney and Reynolds, 1977; Dickinson, 1989). The flattened dip of the downgoing slab caused the zone of slab-induced crustal melting to migrate eastward, and large stocks be be intruded in Arizona and New Mexico (Coney and Reynolds, 1977; Keith, 1978; Dickinson, 1989). In the Rocky Mountains, this time of deformation is called the Laramide orogeny, which is generally Late Cretaceous to Eocene in age. However, the age varies with respect to location. The Laramide orogeny affected the Cordillera of North and Central America,

including the western U.S. and south-central and southern parts of New Mexico, at various times throughout the late Mesozoic and early Cenozoic (**figure 1-5**). Features present in southern New Mexico that resulted from this northeast-directed compression include intrusive and volcanic centers, asymmetric block uplifts, basins filled with debris from the uplifts, northwest-trending faults, and overturned and tightly folded, northeast-verging folds and monoclines, some of which may have been Precambrian structures that were reactivated in Laramide time. Porphyry copper deposits in New Mexico and Arizona (as well as in other parts of the North American cordillera) were formed during the Laramide orogeny.

Pennsylvanian and Permian structures south of the study area may have been overprinted in Laramide time by thrusting. Uplifts formed during Laramide orogeny are northwest-trending, typically, and are flanked by parallel basins; examples include the Rio Grande uplift and Potrillo basin, Love Ranch basin, Hidalgo uplift, Alamo Hueco basin, and Ringbone basin, and the reactivated Burro uplift (Seager and Mack, 1986).

Upper Cretaceous rocks overlain by thick sequences of slightly younger synorogenic rocks are preserved within Laramide intermontane basins. Late Cretaceous sequences are unconformable on older rocks. Upper Cretaceous formations include both marine and terrestrial sediments such as the Beartooth Quartzite, Sarten Sandstone, Dakota Sandstone, and overlying Colorado Formation and Mancos Shale. Latest Cretaceous and Tertiary (Eocene) rocks include interfingering andesitic volcaniclastic rocks, other sedimentary deposits, and redbeds and conglomerates derived from Laramide uplifts. Laramide sediments on the cratonal areas were thinner than those deposited in the foreland basins bordering the craton to the south. Laramide uplifts were basement-cored and bordered by monoclines and steeply-dipping reverse faults.

The culminating part of the Laramide orogeny, during the Paleocene to Early Eocene, has been called the Cordilleran orogeny by some workers. The Cordilleran orogen in southwestern New Mexico is hypothesized by Drewes (1989) to include a more deformed, generally overlying terrane to the southwest abutting a less deformed, generally underlying terrane to the northeast. This orogenic belt thins to the northeast (towards the craton) and is characterized by widespread detachment between the basement and overlying rocks. The detached rocks have been thrusted into a stack of sheets with hundreds of miles of cumulative horizontal offset (Drewes, 1989). A key element in this idea is large-scale horizontal shortening of the rocks by thrusting over the detachment zone between basement and overlying rocks. Workers in cratonal or foreland areas propose a major component of compression-driven, basement-cored uplift, with only a subsidiary component of horizontal crustal shortening as a result of uplift (e.g., Woodward, 1978; Seager, 1983). In this structural setting, inhomogeneous response to compression results in homoclinal

tilting, high-angle reverse faulting, strike-slip faulting, and cylindrical folding (Davis, 1979; Sawyer and Pallister, 1989).

Late Laramide deposits signal early Tertiary erosion in southern and western Arizona, a cessation of arc magmatism in the Cordillera, and peak Laramide deformation in the central Rocky Mountains north of the study area (Chapin and Cather, 1981; Dickinson, 1989). Northeast-directed compressional stresses gradually diminished during a 5-m.y. period in the middle Eocene. Resultant mountain ranges were subjected to a long period of erosion that ensued until about late Eocene time. Coincidentally, arc magmatism ceased within the Cordillera of the western U.S. (Dickinson, 1989).

Post-Laramide Events and Structures— Mogollon-Datil Magmatism

Beginning in latest Eocene or early Oligocene time in southwestern New Mexico, widespread calc-alkalic volcanism took place and caldera and batholithic complexes were formed (**figure 1-6**). Eruption of andesitic volcanic complexes took place to the southwest and a field of volcanoes formed on the craton. Deposition of great thicknesses of volcanic and volcaniclastic debris buried deposits of Laramide age over a regional unconformity that was rather flat and featureless (Keller and others, 1990).

Keller and others (1990) designate the late Oligocene and early to middle Miocene as "early Rift," a period of generally ENE-WSW extension in the study area. During this time, the period of explosive volcanism gradually ceased, and was replaced by regional extension and formation of Basin and Range and Rio Grande Rift structures. Bimodal basalt-rhyolite volcanism accompanied rifting, and continues today in the Rio Grande Rift of New Mexico.

The Mogollon-Datil volcanic rocks and their extension into the mountain ranges of the "bootheel" area of New Mexico comprise the largest remnants of post-Laramide volcanic field within the Mimbres Resource Area. Uplift was associated with and resulted from the volcanic and intrusive events, followed by erosion and deposition of thick volcaniclastic deposits. Volcanic and volcaniclastic tuff deposits blanket large areas of the Mogollon-Datil field in the Mimbres Resource Area, and may indicate, by their varying thicknesses and depositional structures, the locations of source calderas.

Mogollon-Datil Volcanic Field

Mogollon-Datil volcanic field is the largest in a series of middle Tertiary volcanic fields that border the Colorado Plateau structural province in Colorado, Utah, Arizona, and New Mexico (**figure 1-6**). Although not clearly delineated, the Mogollon-Datil field, including the volcanic fields in much of Grant County and the bootheel area of southwestern New Mexico, encompass at

least 51,500 km^2 (Ratté and others, 1984; McIntosh and others, 1992; Luedke, 1993). The volcanic rocks range in age from Eocene to Oligocene. A detailed eruptive history of the volcanic rocks in the Mogollon-Datil field, exclusive of the bootheel area, is given in Ratté and others (1984) and McIntosh and others (1991).

Calderas

Violent volcanic eruptions occur when molten magma reaches the surface. The sudden decrease in confining pressure causes degassing (mostly water and carbon dioxide gas) of magma (Pallister and du Bray, in press). Gas-charged magma may expand to as much as 50 times its original volume, causing a series of explosive eruptions that can bury vast regions of the surface under a thick blanket of hot ash and pumice. Evidence from the geologic record indicates that catastrophic eruptions within the San Juan Mountains of Colorado from the San Juan caldera vented as much as 2000 km^3 (500 mi^3) of magma (Smith and Bailey, 1969). Terrestrial calderas may be as much as 95 km in diameter (Pallister and du Bray, in press). An understanding of the details of their evolution and the type and distribution of deposits resulting from eruptions within the caldera aids in their recognition in the field. Caldera-related rocks are of importance from a mineral-resource standpoint, because ore deposits are often associated with some calderas.

A caldera is a large volcanic depression, which may include one or more vents, that collapsed during eruption of ash-flow tuff. Ash-flow tuffs include a thick *caldera facies*, deposited in or near the caldera and a second, thinner *outflow facies* deposited beyond the caldera rim (Smith and Bailey, 1968) (**figure1-7**). Central caldera facies rocks may be secondarily uplifted into a *resurgent dome*. The resurgent dome is surrounded by *moat deposits* composed of pumice, volcaniclastic sediments, landslide debris, and lake deposits. *Ring fractures*, which encircle the central dome, and *radiating fractures* extending from the dome, are the conduits for additional plugs, dikes, and domes. In the subsurface, the caldera fill is separated from an underlying magma source or stock by a layer of pre-caldera rocks (such as country rock) that are invaded by sills and dikes.

Typically, calderas are formed by collapse of the underlying magma reservoir during the explosive evacuation of rhyolitic and dacitic ash from the chamber (**figure 1-8**). At times, resurgent magmatic pressure caused formation of domes within collapsed calderas. After formation of the caldera and the possible resurgent dome in each complex, eruption continued from the ring complex surrounding the caldera. Ash deposits accumulated within the moat area and eventually buried previous deposits and the possible resurgent dome. A period of basaltic volcanism could take place, with eruption of mainly andesitic and dacitic to basaltic deposits causing burial of the caldera-related deposits. Tholeiitic and alkali olivine basaltic (silica-poor)

rocks and rhyolitic (silica-rich) rocks may be deposited in close proximity (termed bimodal volcanism) in the form of flows, domes, tuff rings, and plugs. Bimodal volcanism of this type is characteristic of Basin-and-Range extension and rifting in New Mexico.

Numerous calderas and caldera complexes in the Mimbres Resource Area and adjacent parts of Arizona have been described (**figure 1-6**; du Bray and Pallister, 1991, 1992; McIntosh and others, 1992; Luedke, 1993), although various workers may disagree on their presence, location, and extent. In the Mogollon-Datil volcanic field, caldera complexes include the Mogollon, Bursum, Gila Cliff Dwellings, Twin Sisters, Emory, Schoolhouse Mountain, Good Sight-Cedar Hills (volcanic tectonic depression), Doña Ana, Dagger Flat, Organ, and Ice Canyon calderas (McIntosh and others, 1992). Animas, Peloncillo, Big Hatchet and Little Hatchet, Pyramid, and Cedar ranges contain mid-Tertiary volcanic centers that may be extensions of the Mogollon-Datil field (McIntosh and others, 1992). Volcanic deposits are widely separated in this region, making correlation of the units difficult. Future studies will further identify and define caldera complexes, including Muir, Rodeo, Juniper, Animas Peak, Tullous, Geronimo Trail, Cowboy Rim, and San Luis calderas.

Eruptive activity in the Mogollon-Datil field probably took place from 36-24 Ma (McIntosh and others, 1991), and probably coincided with the cessation of subduction beneath the continent and the initiation of strike-slip movement at the plate boundary (e.g., onset of strike-slip movement along the San Andreas Fault system in California). Development of the Basin-and-Range extensional faulting related to the Rio Grande Rift in New Mexico also began at this time.

Many problems are associated with regional identification of the various tuff units in the Mogollon-Datil field owing to their similarity in tuff composition, geochemistry, and to the complexities in K-Ar radiometric or fission-track dates (McIntosh and others,1992). Tuffs may be widely separated as a result of subsequent deformation and (or) erosion. Source calderas may not have been identified for the various ash-flow tuff sheets and, conversely, calderas exist for which no outflow deposits can be correlated. Modern techniques and methodologies of radiometric dating (i.e., $^{40}Ar/^{39}Ar$ and paleomagnetic dating techniques) may help to resolve these problems.

Geochronologic and paleomagnetic data for volcanic rocks (McIntosh and others, 1992) from the Mogollon-Datil field (exclusive of the fields in the bootheel area of southwestern New Mexico) show that four separate eruptive intervals took place from two parts of the Mogollon Mountains. One area is located south and west of Socorro; the other extends as a band from Las Cruces to Glenwood. Volcanic ash eruption began in the Organ caldera complex (36-35.4 Ma), and subsequently migrate to the northwest to form the Mogollon and Socorro caldera complexes (35-24 Ma). Extensive eruption of flows and domes occurred briefly between the Organ caldera

complexes in the central Black Range and the Mogollon and Socorro complexes during 29.0-28.1 Ma.

Four episodes (pulses) of ash-flow eruption resulting in about 25 high- and low-silica rhyolite ash-flow tuffs, have been described for the Mogollon-Datil volcanic field in the northern and eastern part of the study area (McIntosh and others, 1992):

Pulse 1: Mainly low-silica rhyolite flows were erupted between 36 and 34 m.y. (million yrs before present). At least 11 regional outflow sheets, several smaller local units; and two calderas have been identified with the first episode. Ash-flow tuffs can be categorized as: (1) pre-Kneeling Nun tuffs (36-35 m.y.), that erupted as 7 outflow sheets and one intracaldera sequence; (2) Kneeling Nun Tuff (35 m.y.) that erupted from the Emory caldera in the southern Black Range; (3) post-Kneeling Nun, pre-Box Canyon units, including several tuff units that were erupted from Emory caldera, various calderas in the bootheel area, the Cooney Tuff in the northern part of the field (a long-ranging tuff that erupted from an unknown caldera), and the tuff of Lebya Well, Rock House Canyon Tuff, and Blue Canyon Tuff, which were erupted from unknown calderas; (4) the Box Canyon Tuff, which includes an intracaldera ash-flow tuff of about 34 m.y. from the Schoolhouse Mountain caldera

Pulse 2: Three flow units (the Hells Mesa Tuff from the Socorro caldera north of the Mimbres Resource Area, Caballo Blanco Tuff from an unknown caldera, and the Tadpole Ridge Tuff from Twin Sisters caldera) were erupted between 32 to 31 m.y.

Pulse 3: Between 29 and 27 m.y., the largest eruptions in the Mogollon-Datil field produced 9 ash-flow tuff units. Two groups of calderas were active during these episodes—one in the Mogollon Mountains and one west of Socorro.

Pulse 4: The Tuff of Slash Ranch and the Tuff of Turkey Springs were erupted between 26-24 m.y.

Transition to Basin-And-Range Deformation in Late Tertiary Time; Rift-Related Volcanic and Sedimentary Structures (Mid-Oligocene—About 25 Ma to Recent)

Following the calc-alkalic volcanic and plutonic activity, or partially coincident with it, in Middle Tertiary time, east-west extension began about 30 m.y. ago (Chapin and Seager, 1975; Morgan and others, 1986; Aldrich and others, 1986; Dickinson, 1989; Kelley and others, 1992), that resulted in the Rio Grande Rift zone that spans the state from north to south in the vicinity of the Rio Grande Valley. In the region of the Mimbres Resource Area, the Rift zone is bounded by the Florida, Cookes, and Black Ranges on the west and the Sacramento Mountains on the east (**figure 1-9**). Extensional features (primarily block faulting) resulting from activity on the Rio

Grande Rift are referred to as Basin-and-Range structures and some of the features record several km of dip-slip displacement. In southern and southwestern New Mexico, the southern and eastern boundaries of the Rift zone are diffuse; in the northern part of New Mexico, the Rift boundary is more easily identified.

The Rift in the southern part of the state has been delineated using both geological and geophysical techniques (**figure 1-9**). The Rift is difficult to delineate in the southern part of New Mexico owing to the complexity of tectonic and magmatic features. The Rift in northern Mexico is difficult to delineate owing to the presence a Jurassic evaporite basin within the Chihuahua trough, which extends parallel to and west of the Texas-Mexico border (Gries, 1979). The evaporites behaved plastically under regional high heat flow (a characteristic of the Rift), and masked surficial structural features of extension (Gries, 1979).

Keller and others (1990) have divided rift movement into two stages—"early rift" and "late rift." The Rio Grande Rift evolution is recorded in the rocks of the Uvas Basaltic Andesite and the Gila Conglomerate/Santa Fe Group (**figure 1-3**). Volcanism persisted for almost all of Oligocene time in the vicinity of the Good Sight-Cedar Hills depression, although the source of the volcanic material is unclear. However, nearly continuous deposition within the basin documents the transition from Oligocene volcanism to Miocene and later rifting. In the Good Sight-Cedar Hills depression, Uvas Basaltic Andesite marks initial block-fault movement in the Rio Grande Rift (Chapin and Seager, 1975) (**figure 1-10**). All units thin to the north, south, and west, from the basin axis; the eastern boundary is structurally controlled by the Cedar Hills vent and fault zone, and tuff and flow units are blocked by it. Within the Mogollon-Datil field, extension caused segmentation of the ignimbrite shield into fault-block mountains. Such structural activity resulted in a variety of complexly faulted, tilted mountain ranges juxtaposed against unfaulted, flat-lying, and relatively undeformed ranges throughout the western part of the study area (**figure 1-6**) (McIntosh and others, 1992). Uplift of the Colorado Plateau in northwestern New Mexico and adjacent parts of Colorado, Utah, and Arizona, apparently took place concurrently with formation of the "early rift" basins in Oligocene time. Culmination of rifting took place in latest Miocene and (or) Pliocene time ("late rift") (Chapin and Seager, 1975)(**figure 1-3**).

Rifting took place in part along pre-existing structures that were deformed during late Paleozoic and Laramide times, and further segmented the Laramide and younger mountain ranges. A consequence of rifting was development of a characteristic north-south trend of structures within each mountain range, which overprinted the typically northwest to westerly trend of Laramide and pre-Laramide structures. Some Basin-and-Range faults may be reactivated Laramide structures, although differentiating the ages of movement is difficult. Within the Rift, a series of structural

(graben and half-graben) basins developed, including the Jornada del Muerto, Tularosa, and Mesilla basins within the study area (Ryder, 1983), and tilted fault blocks were formed, such as the San Andres-Organ-Franklin Mountains chain. According to Keller and others (1990), "early rift" basins of Oligocene age (Keller and others, 1990) were modified in Miocene time by accelerated faulting, modification during this second stage of rifting of the "early rift" basins (mentioned above), and a change in stress orientation from NW-SE to nearly E-W.

In southwestern New Mexico, rifting occurred between 20 and 10 m.y. ago (Coney, 1978; Eaton, 1979; Ryder, 1983). Rift basins in this area are typically shallower than those in the Rift zone along the Rio Grande (Seager and Morgan, 1979). Bimodal basalt-rhyolite was erupted during extension of the Rift less than 25 m.y. ago. These ash-flow tuffs and basalts are less extensive and more silicic than rocks of the Mogollon-Datil province.

Coincident with extensional tectonism in southern and southwestern New Mexico was the development of fans and pediments on the flanks of mountain ranges, development of deep, bolson-type (internally drained) basins, entrenchment of the ancestral Gila River and Rio Grande, development of local small fault scarps, and eruption and intrusion of mafic and silicic rocks.

According to Keller and others (1990), the last period of volcanism along the Rift began about 12-14 m.y. ago, when the upward movement of mantle material and development of a new thermal regime related to the shallowing Rift zone was initiated. This later period of rifting (between about 10 m.y. and 3 m.y.) is referred to as "late rift" (Keller and others, 1990). Volcanic centers developed where major lineaments intersected the Rift (north of the Mimbres Resource Area in the central and northern parts of the Rift zone in New Mexico and Colorado), followed by basaltic volcanism and local maar development, which has been especially prevalent during about the past 5 m.y. (Keller and others, 1990). High-angle faults that bound the ranges and cut the earlier northwest-trending faults are used to document this period of movement. Some of the fault movement extends into late Quaternary time. In the Mimbres Resource Area, good evidence for this last period of rifting is in the fault scarps along mountain fronts and the presence of basaltic outflows, such as the Potrillo Mountains basalt field (**figure 1-11**).

Cessation of extension after about 5 m.y. ago probably allowed through-going drainages to form, possibly allowing entrenchment of the Colorado River into the Colorado Plateau (forming the Grand Canyon), as well as entrenchment of the Gila River and Rio Grande in southern and southwestern New Mexico.

MINING HISTORY OF THE MIMBRES RESOURCE AREA

Virginia T. McLemore, NMBMMR,

INTRODUCTION

The Mimbres Resource Area of the BLM includes all of the most mineralized area in New Mexico and the highest metallic mineral production in the State. Mining has been an integral part of the economy of the Mimbres Resource Area since pre-historic times. Mining districts are numerous (**table 1-2**; **figure 1-12**) and several world-class ore deposits were discovered in the region. Twenty five types of deposits (see Sutphin, this volume) occur within the Mimbres Resource Area.

Mines in the study area account for most of the copper and zinc production in New Mexico as well as significant gold, lead, and silver production. Total production from the Mimbres Resource Area is estimated to amount to 15.7 billion lbs of copper, 100 million oz of silver, 1.2 million oz of gold, 651 million lbs of lead, and 2.8 billion lbs of zinc. This accounts for more than 90 percent of the total copper, zinc, and silver production from New Mexico (from 1848 until 1993), 89 percent of the lead, and 46 percent of the gold production. Other commodities have been produced as well.

Production figures are the best currently available data and were compiled from NMBMMR file data from a variety of published and unpublished sources (**table 1-3**; tables 1-4 through 1-9, compiled from NMBMMR file data). Mining records, and especially production records, are missing for most, and are incomplete and equivocal, particularly for the earliest times.

Metal mining operations are in the Silver City area (Chino, Tyrone, Continental mines) and in the Lordsburg and Steeple Rock districts presently. Manganese is produced sporadically from government stockpiles in Luna County.

EARLY MINING ACTIVITIES

Native Americans were the first miners in the area and used local sources of hematite and clay for pigments. Their houses were made of stone, adobe, and clay (**figure 1-13**). Clay was also used in making pottery. Stone tools and arrowheads were shaped from local deposits of pebbles, jasper, chert, and obsidian.

The first commercial mining by Native Americans was to obtain turquoise for trading and making ornaments. The common occurrence of charcoal at old mines suggests that simple heating of the rock was used to free the valued blue-green turquoise; charcoal was also necessary for smelting and working iron and steel (i.e., blacksmithing). Native copper was mined and traded. However, they did not mine great quantities of minerals. Vast deposits were left for future generations of Spanish, European, and American miners.

Spanish explorers first entered New Mexico in 1534 with the expedition led by Alvar Nuñez Cabeza de Vaca, which was soon followed in 1539 by Fray Marcos de Niza. Francisco Vasques de Coronado led an expedition in 1540 looking in vain for gold and silver (Jones, 1904; Christiansen, 1974). Coronado did find turquoise, which led the way to future colonization. Early Spanish mining in New Mexico was centered around the Cerrillos and Old Placers districts in Santa Fe County in north-central New Mexico, but some activity occurred as well near Silver City within the Mimbres Resource Area. The Pueblo Revolt in 1692 has been partly attributed to Spanish enslavement of the Native Americans into mining, but there is little documentation of such activity (Jones, 1904; Northrop, 1959).

Probably the earliest mining by the Spanish in the Mimbres Resource Area was for turquoise in the Burro Mountains and Santa Rita areas (Paige, 1922; Gillerman, 1964). However, mining by the Spanish in the study area did not amount to much until about 1798 when an Apache told Colonel Manuel Carrasco about copper deposits near Santa Rita. Carrasco interested Francisco Manuel Elguea in forming a partnership and they obtained a land grant, the Santa Rita del Cobre Grant, to pursue copper mining. By 1804, Elguea bought out Carrasco's share and began mining copper in earnest. Elguea found a ready market for copper in Mexico City. Actual production records are lacking, but Christiansen (1974) estimates 200 mule trains were shipped annually, amounting to about 6,000,000 lbs of copper per year; this estimate may be exaggerated. The expedition of Lieutenant Zebulon Pike in 1807 also encountered mining at Santa Rita (Jones, 1904). Ore was shipped with little or no processing, and what processing that was required involved smelting in simple adobe furnaces. Elguea died in 1809 and mining at Santa Rita diminished as a result of increasing costs, difficult transportation, Native American uprisings, declining copper demands in Mexico and, finally, the Mexican Revolution of 1810. The records are conflicting as to who owned and operated the mines after 1809, and the mines finally closed in 1834. They were still inactive when the Army led by General Stephen Watts Kearney visited the area in 1846 (Jones, 1904; Milbauer, 1983).

In 1848, New Mexico became part of the United States Territory and the mining industry became a dominant force in the state. Written records of mining activity and production were rarely preserved and conflicting early accounts exaggerate the mineral wealth in New Mexico. At first, mining was by small groups of individuals; large mining companies were not formed until the late 1880s. Gold was discovered in the Ortiz Mountains in north-central New Mexico in 1828 (Jones, 1904; McLemore, 1994a) and drew an estimated 2,000-3,000 miners to that region. When the gold played out at Ortiz, many of these miners began prospecting throughout New Mexico, and especially within the study area boundaries. In the 1850s, prospectors heading for the gold fields

in California travelled the state, found New Mexico to their liking, and stayed.

Prospectors discovered the mineral deposits in the Organ Mountains in the 1830s. The Stevenson-Bennett mine, the largest in the range, was discovered in 1849 (Dunham, 1935; Eveleth, 1983). Placer gold was mined from the Piños Altos district in 1860, when more than 700 miners were working in the district (Milbauer, 1983) (**table 1-4**). Mining began in the Fierro-Hanover district in 1850, Bayard district in 1858, and Piños Altos, Fremont, and Steeple Rock districts in 1860 (**table 1-2**). Mining had resumed at Santa Rita by the late 1850s, but was interrupted by the Civil War and the need for soldiers in the eastern United States. All mining within the Mimbres Resource Area ceased in 1862 with the invasion of New Mexico by Confederate forces (Milbauer, 1983). The Civil War depleted the number of soldiers in the state, and the mining camps were no longer safe from Apache raids. Thus, many districts remained inactive until after the war.

MINING AFTER THE CIVIL WAR

The end of the Civil War brought change to the mining industry in New Mexico. By the late 1800s, better records were kept and preserved for the future. Settlers and prospectors fled the war-torn east to start new lives in the west. Soldiers were sent to New Mexico and Arizona to eliminate interference by Native Americans. The area encompassed by the Mimbres Resource Area was one of the last in the United States to be under the threat of attack and many mining districts were not discovered until 1890-1900.

The Federal Mining Act of 1866 established rules and regulations governing prospecting and mining, with certain provisions to obtain private ownership of federal land containing valuable mineral resources. The act was amended in 1870, 1872, and in subsequent years. The mining act further encouraged mining and prospecting within the boundaries of the Mimbres Resource Area. Times were exciting for the miner in the late 1800s as metal prices soared. Large mining companies were formed to develop the larger deposits. When the mining boom of 1870-1890 began, the threat of attack by Native Americans waned. Construction of telegraph and railroad improved communication and access to the area. New metallurgical techniques were developed. The cyanide process was perfected in 1891, which revolutionized gold recovery.

The 1870s and 1880s saw rapid growth in many districts. In 1873, M.B. Hayes began mining at the Santa Rita mine. The mine changed owners several times from 1881 to 1904 (Sully, 1908). The railroad was completed to Lordsburg in 1881, to Hanover in 1891, and to Santa Rita in 1899 (Sully, 1908; Christiansen, 1979), making ore production more profitable. Silver was discovered in the Black Hawk district in 1881, and gold was found in the Malone and Gold Hill districts in 1884 (Gillerman, 1964). In the 1880s, fluorite was mined for smelter flux at the Burro

Chief mine in the Burro Mountains district and at the Foster mine in the Gila Fluorspar district (Gillerman, 1964; Williams, 1966). Iron ore was also mined and used for smelter flux (Harrer, 1965).

Silver became important from the 1870s to the 1880s in many districts. Silver was discovered in the Chloride Flat district in 1871, which probably produced $4 million worth of silver prior to 1893. Lead-zinc-silver deposits in the Cookes Peak district yielded about $3 million by 1900. In 1882, horn silver was found in the Telegraph district with assays as high as $300-$500/short ton (Northrop, 1959). Georgetown produced $3.5 million worth of silver prior to 1893 (Anderson, 1957). In 1890 the Sherman Silver Act was passed, increasing the price and demand for silver. However, the demand for silver was short-lived. The Sherman Silver Act was repealed in 1893 and most silver mines in the southwest closed, never to reopen. A depression resulted and, in some districts, only gold ore was of importance. Hanover mines were idle during most of the 1880s, but in 1891 markets developed for iron and zinc, and Hanover mines began producing again. Manganese was produced from the Chloride Flat district in 1883-1907 and was used in smelters in the Silver City area (Farnham, 1961; Dorr, 1965). However, by 1900, there was little activity in most of the Mimbres Resource Area.

MINING IN THE TWENTIETH CENTURY

New mining and milling technologies were developed throughout the twentieth century that encouraged exploration and development of many deposits in the Mimbres Resource Area that had been ignored in the 1800s (**figure 5-1.28** and **figure 5-1.29A**). But booms and busts were the norm for most mining towns because both World Wars I and II, along with financial slumps, controlled the metals markets. New commodities such as manganese, uranium, and barite were also in demand.

In 1904, Daniel C. Jackling opened the first large, open-pit mine to produce low-grade copper ore (less than 2 percent Cu) at Bingham Canyon, Utah. At the same time, John M. Sully arrived at Santa Rita and recognized the similarity of ore at Santa Rita to that mined at Bingham Canyon. Sully thoroughly explored the area, and finally, in 1909, he obtained financial backing (Sully, 1908). In 1910, production began. The first concentrator mill was erected at Hurley in 1911; flotation concentration was added in 1914 (Hodges, 1931)(**figure 1-14**).

Other commodities were developed (**table 1-5**, **table 1-7**, and **table 1-9**). Fluorite was discovered and mined at Fluorite Ridge in 1909 and manganese was produced from the Little Florida Mountains in 1918 (Griswold, 1961). In 1916, manganese production resumed throughout the Mimbres Resource Area for use as smelter flux at Pueblo, Colorado (Dorr, 1965).

New Mexico became a state in 1912, and in 1914 World War I began. Metal prices and production increased as metals were needed for the war effort. Annual production of minerals valued at over $43 million was at all time high in New Mexico, and much of that production came from within the study area boundaries (**table 1-3**). In 1918, World War I ended and was followed by a depression, which closed many of the mines in the region (Northrop, 1959). Fluorite was produced from the Cookes Peak district in 1918 and from the Tonuco and Tortugas Mountains districts in 1919 (**table 1-5**). Ground Hog mine in the Fierro-Hanover district began production in 1928. In 1930, the price of copper dropped from $.18/lb to less than $.10/lb, but production continued at the big mines in the area. Copper was only $.05/lb in 1932, forcing most of the mines to close (Northrop, 1959). Recovery did not occur until 1938.

World War II began in 1940 and, once again, the war increased demand for metals. On October 6, 1942, the U.S. War Department closed all gold mines in the U.S. Only base metals and other strategic minerals such as tin, tungsten, manganese, beryllium, fluorite, and iron were mined (**table 1-5**, **table 1-8**, and **table 1-9**). Exploration for these commodities increased, and many mines went into production. When the war ended in 1945, the Federal ban on gold mining was lifted.

Mining in the Mimbres Resource Area continued after the war; booms and busts in exploration and production continues to be the trend. Drilling in the Piños Altos area by the U.S. Mining, Smelting, and Refining Co. in 1948 encountered lead-zinc ore bodies that are now being mined by Cyprus Metals Co. (Osterberg and Muller, 1994). In 1951, the Federal government initiated incentive buying programs for domestic production of manganese (DeVaney and others, 1942; Agey and others, 1959), tungsten, and uranium. Manganese and uranium mines in the area went into production and exploration intensified (**table 1-6** and **table 1-9**). Termination of the Federal programs in 1956 (tungsten), 1959 (manganese) and 1965 (uranium) effectively closed these mines. Most districts in the area saw some exploration when various companies examined the area looking for the missed deposit. But most districts have seen insignificant metal production since the 1950s (**table 1-2**, **table 1-3**). Industrial minerals became important in the 1970s (**table 1-5**, **table 1-7**).

Since 1950, most metals mining activities have taken place in the Silver City area; today activity is centered in the Chino, Tyrone, Continental, Piños Altos districts and in the Lordsburg and Steeple Rock districts (See Mineral Deposits section, this volume). Manganese is sporadically produced from Luna County. Industrial minerals are important commodities, especially scoria, sand, and gravel.

MINING METHODS

The earliest mining methods were crude and simple, having been extracted with simple tools. Locally, rock was broken and metals recovered by heating using fire and by quenching. Mechanized production methods were not common until the 1880s.

Although most ore found in the early years occurred at the surface, in later years, underground shafts were common, connecting working level drifts, raises, and haulage drifts. Eighty-Five and Booney mines in the Lordsburg district are the deepest shafts in the Mimbres Resource Area with workings to 500m and 670m, respectively (Yountz, 1931). Most underground mining utilized shrinkage and cut-and-fill techniques. Square-set techniques were used only on rare occasions, owing to the high cost of lumber in southwest New Mexico. Only four stopes utilized square-set timbering in 11 years of mining at the Eighty-Five mine (Yountz, 1931).

The Silver City area is well known for large open-pit operations, such as at Santa Rita (Chino), Tyrone, and Continental mines. However, most of the early production at these and other mines was by underground methods. Open-pit mining began at Santa Rita in 1910 (Thorne, 1931).

ORE PROCESSING

Initially, ore processing techniques were simple, requiring only crude adobe smelters (Christiansen, 1974). Gold was processed using stamp mills-- or arrastra mills (**figure 1-15**). In the late 1800s, mills and smelters were built in most of the major mining districts (**figure 1-16**).

The Federal Mining Act of 1872 established procedures for patenting a millsite. Many millsites were patented, but the records are not always clear as to what kind of mill, if any, was established or if the mill operated. Mill histories are difficult to trace because ownership changed; mills were typically dismantled at one site and rebuilt at another site. Most early mills were associated with a specific mine, but by the late 1800s, mills were established in or near large districts and would custom-mill ore from distant locations. Selected mills are listed in **table 1-10**, and mill locations are shown on **figure 1-16**.

The Deming area has been the site of numerous mills since 1928 when the Peru mill was first built. American Smelting and Refining Company (ASARCO) built a mill in Deming in 1949. Both mills processed lead-zinc ores from the Silver City area. Manganese was concentrated and shipped from a purchasing depot in Deming from 1953 to 1955 (Agey and others, 1959). Deming has abundant groundwater, adequate area for disposal of tailings, and is accessible to the railroad (Griswold, 1961). Cyprus mill and Hurley and Playas smelters are active. In addition, two processing plants operate in El Paso: ASARCO's El Paso smelter (copper) and the Phelps Dodge

Corporation El Paso Works (430,000 short tons copper per year by the solvent extraction-electrowinning process).

MINERAL DEPOSIT MODELS

by David M. Sutphin
U.S. Geological Survey, Reston, VA

INTRODUCTION

Mineral deposit models are tools that are used both in mineral exploration and resource assessment. They consist of lists of characteristics that can be used to classify the mineral deposits and occurrences and to predict geologic environments where undiscovered deposits may exist. Described herein are deposit models that represent, with few exceptions, the spectrum of mineral deposits that are known to occur, or that may occur, in the Mimbres Resource Area. Most of the models described herein rely on previously documented deposit types; for example, porphyry copper deposits (Cox, 1986). Deposit models may be indicated by number and reference in succeeding sections of this report.

Each deposit-model description provides characteristics of the deposits in the model, a description of the geologic environment that is permissive for the occurrence of each mineral deposit, and graphs showing the expected grade and tonnage of each deposit type. If a previous assessment of a part of the study area has outlined an area permissible for that deposit type, a brief summary of that assessment is included. A brief summary of the economic significance of the deposit type is included to provide a sense of its relative importance to the economy. The purpose of this section is to bring together information on the deposit models, so that it is clear to the reader what any single deposit model means with regard to the geologic characteristics of the area, the ranges in grades and tonnages in the deposit model, and the economic significance of any deposit type occurring or having the potential to occur in the study area. Deposits lacking a deposit model are not discussed here.

Deposits in various mining districts in each of the four counties are described in following sections of this report, where they are classified according to deposit type. Permissive tracts, nonpermissive tracts, and favorable areas are delineated, and quantitative estimates are made of the undiscovered resources contained in the study area (see Assessment section, this report).

Mineral deposit types are grouped according to their general characteristics (**table 2-1**). The deposit groups include porphyry deposits (porphyry-copper and porphyry-molybdenum deposits), hydrothermal and epithermal vein deposits, carbonate-hosted deposits, including replacement deposits and several types of skarn deposits, and other types of deposits that encompass rhyolite-hosted tin, gold placer, and gypsum deposits.

Most mineral deposits in the Mimbres Resource Area are directly related to igneous activity and owe their ultimate origin to processes that originate in the Earth's crust or mantle. As a

consequence of this deep origin, the geologic terranes in which mineral deposits occur are sometimes difficult to define. In many cases, mineral deposits may be recognized owing to the localized anomalies caused by igneous activity. Thus, many of the deposit types discussed here are metallic and industrial mineral deposit types related to igneous activity.

Deposit types whose genesis bears no apparent or direct relation to igneous activity are also found in the study area. Geologic environments for these deposit types may be specified with a great degree of precision, because, although not strictly syngenetic, they formed as a result of geologic processes occurring throughout broad regions of the Earth's crust—processes that often leave other clues in the rocks. On a regional basis, it may be relatively easy to define permissive environments for these deposits.

PORPHYRY DEPOSITS

Porphyry deposits are hydrothermal deposits associated with intrusions of porphyritic igneous rock. A wide variety of metals and styles of mineralization form in this environment. Copper is usually present; zinc and silver are often associated; lead is present if carbonate rocks are hosts; and molybdenum is commonly present. Porphyry deposits are the sole source of molybdenum (Meyer, 1981). Because porphyry deposits are large in size, have significant metal content, and are amenable to low-cost extractive methods, they have been subject to widespread exploration over the last 40 years, with parts of the study area having been sites of major production from deposits of this type. Porphyry deposit types occurring or permissible in the study area include porphyry copper; porphyry copper-molybdenum; porphyry copper, skarn-related; and porphyry molybdenum, low-fluorine. In the computer simulation used in this assessment, the porphyry copper-molybdenum deposit model was used to represent all porphyry copper deposit types, since determination of whether an undiscovered porphyry copper deposit was more likely to be a porphyry copper, porphyry copper-molybdenum, or porphyry copper, skarn-related deposit was beyond the assessors' capability.

PORPHYRY COPPER

Characteristics

Porphyry copper deposits are bodies of fracture- and veinlet-controlled disseminated copper sulfides and are the products of large intrusion-related hydrothermal systems. The deposits consist of stockworks of quartz veins that contain mainly chalcopyrite and bornite as primary ore minerals, and occur in hydrothermally altered porphyries and adjacent country rocks. They are known to occur along convergent plate boundaries (Cox, 1986). Titley and Beane (1981) note that, in their simplest form, porphyry copper deposits are related to the thrusting of oceanic crust beneath continents, where the oceanic crust melts at depth and gives rise to metal- and water-rich

calc-alkaline magmas. These magmas rise to the shallow crustal environment and become the igneous predecessors to porphyry-copper systems. The metals in these systems—copper, molybdenum, silver, lesser gold, and platinum-group metals—are believed to have been derived from the oceanic ridges; they were transported within the oceanic crust and within the thin layer of oceanic sediments resting on the crust. Sillitoe (1975) proposed that zonation of the different types of porphyry copper deposits in North America is the result of the sequential release of metals as the subducted slab of oceanic crust is melted. Other sources of the metals in porphyry copper deposits, such as the crust or the mantle, have been proposed, but the answer remains in doubt. It does, however, seem clear that development of porphyry copper deposits is inextricably involved with plate tectonics (Titley and Beane, 1981).

Titley and others (1989) cite three essential and unifying characteristics common to porphyry copper systems. First, these deposits are found associated with a small (1-2-km diameter) porphyry intrusion that is usually central to zoned alteration and metals. In the American Southwest, this intrusion is almost always of Laramide age. Second, both alteration and metal mineralization are fracture controlled; the rocks are highly shattered. Fractures occur in the central porphyry mass, but commonly extend outward for kilometers. Third, porphyry copper systems exhibit zonation in both the alteration and distribution of metal abundances and types. In many districts, porphyry copper deposits form the core of base- and precious-metal districts.

Kirkham and Sinclair (1984a) report that, in magmatic-hydrothermal systems where these deposits form, large volumes of saline aqueous solutions migrate under high pressure upward and outward from a magma. Once emplaced at shallow levels and fractured, magmas have extensive hydrothermal interaction with their host rocks. Host rocks are extensively fractured, brecciated, and hydrothermally altered. Alteration is extensive, and typically consists of an inner zone of potassic alteration surrounded by propylitic alteration associated with pyrite. Phyllic and argillic alteration may be present. Ore is structurally controlled, forming stockwork, vein, disseminated, and replacement deposits. Skarns may develop where intrusives encounter carbonate rocks. Chalcopyrite, bornite, other copper minerals, and native gold are ore minerals; pyrite and other sulfides are gangue, along with magnetite, quartz, biotite, potassium feldspar, epidote, and garnet. Economic porphyry copper deposits are typically Mesozoic or Tertiary in age. In some porphyry copper deposits, mineralization may be concentrated by supergene enrichment; however, long periods of extensive erosion will destroy deposits of this type.

Richter and others (1986) identified several criteria for discovering porphyry copper deposits in the Silver City quadrangle that can be used throughout the study area:

-- Late Cretaceous-early Tertiary volcanic terranes intruded by cogenetic granodiorite-quartz

monzonite porphyries

-- potassic and phyllic hydrothermal alteration

-- copper vein deposits

-- broadly anomalous Pb, Zn, Ba, Mn, ±Cu, Ag, and Sn in either magnetic or nonmagnetic fractions of panned stream sediments

-- locally anomalous Pb, Cu, Ba, Mn, Zn, Ag, ±Mo, Be, and Sn in magnetic fraction of panned stream sediments

-- pervasive propylitic alteration

-- Late Cretaceous-early Tertiary volcanic terranes without known associated hypabyssal or plutonic rocks

-- base- and precious-metal vein deposits

-- covered or nonexposed plutonic rocks inferred from gravity or magnetic anomalies

-- northeast-trending zones of structural weakness inferred from gravity or magnetic features.

Porphyry copper is a general deposit type consisting of several subtypes of deposits (**table 2-2**). For example, porphyry copper deposits having a substantial concentration of molybdenum or gold are termed porphyry copper-molybdenum or porphyry copper-gold deposits, respectively. Those having a substantial skarn component are termed porphyry copper, skarn-related. These subtypes have the same primary characteristics as porphyry copper deposits, but differ in detail from the original porphyry copper deposit model.

Assessments of both the Douglas and Silver City quadrangles speculated on the presence of undiscovered porphyry copper deposits. In the Douglas quadrangle, Hammarstrom and others (1988) determined that the Little Hatchet Mountains, including the Eureka and Sylvanite districts, were favorable for the occurrence of porphyry copper and porphyry copper, skarn-related deposits. In the Silver City quadrangle, Richter and others (1986), delineated several areas favorable for the occurrence of porphyry copper deposits, including an area stretching from Lone Mountain district to beyond the Georgetown district, Pinos Altos district, Burro Mountains, Lordsburg district and surrounding area, and the central Peloncillo Mountains.

Grades and Tonnages

Porphyry-copper deposits are typically large-tonnage, low-grade deposits that are amenable to open-pit mining methods that take advantage of the economies of scale. Some deposits are mined using in-situ mining techniques. Lengths and widths of the deposits are usually measured in the thousands of meters and the thicknesses are in hundreds of meters. The grade-and-tonnage model for porphyry copper deposits indicates just how large these deposits are (Singer and others, 1986). The median tonnage is 140 million tonnes. Ninety percent of the deposits contain 19

million tonnes or greater, and 10 percent contain 1,100 million tonnes or greater. The median copper grade is 0.54 percent Cu. Ninety percent of the deposits contain 0.31 percent Cu or greater, and 10 percent contain 0.94 percent Cu or greater. Ten percent of the deposits contain 0.03 percent Mo, 0.4 grams per tonne (g/t) Au, and (or) 2.6 g/t Ag. The grades and tonnages of porphyry copper deposits and the subtypes are shown in **table 2-2**.

Economic Significance

Porphyry copper deposits are the most important deposit type in the American Southwest. The presence of this type of deposit has made copper the premier metal commodity produced in the study area, and the known porphyry copper deposits in the area contain a very large copper resource. On a worldwide basis, deposits of this type are estimated to contain 60 percent of the world's copper reserves (Kirkham and Sinclair, 1984a). Molybdenum, gold, and silver may be important byproducts, and lead, zinc, silver, and manganese deposits may be peripheral to the porphyry deposit. Despite this production, the United States has a net import reliance of 6 percent for copper (U.S. Bureau of Mines, 1994, p. 54).

PORPHYRY COPPER SKARN-RELATED

Characteristics

Porphyry copper skarn-related deposits are porphyry copper deposits that occur in carbonate or calcareous clastic rocks and have an abundance of calc-silicate minerals such as andradite garnet, diopside, wollastonite, and tremolite (Cox, 1986). They consist of chalcopyrite and other copper minerals in a stockwork of veinlets in hydrothermally altered intrusive rocks, tonalite to monzogranite, and in skarn with extensive retrograde alteration. Deposits form when large volumes of highly saline aqueous magmatic hydrothermal fluids migrate under high pressure upwards and outwards from a pluton. Extensive fracturing, brecciation, and calc-silicate alteration are associated with ore formation. Alteration may be zoned, with potassic alteration in the pluton being associated with andradite garnet and diopside in the carbonate or calcareous rocks. Farther from the contact between the pluton and the host rocks, wollastonite or tremolite are the dominant calc-silicate minerals in the calcareous rocks, with minor garnet, idocrase, and clinopyroxene. This zone grades outwards into marble. Subsequent weathering may enrich the deposits. Associated deposit types are copper skarns and polymetallic replacement deposits.

Listed below are several criteria for identifying porphyry copper, skarn-related deposits in the study area (Richter and others, 1986):

-- intrusion of tonalite to monzogranite into carbonate rocks or calcareous clastic rocks
-- presence of calc-silicate minerals
-- potassic alteration of the pluton and the association with andradite and diopside in the

calcareous rocks; phyllic alteration in the pluton and the association with retrograde actinolite, chlorite, and clay in the skarn

-- intense stockwork veining containing copper minerals

-- gradation of calc-silicate alteration into marble.

Grades and Tonnages

Porphyry copper, skarn-related deposits are mined in the same manner and are of similar size as other porphyry copper deposits. The grade-and-tonnage model for porphyry copper, skarn-related deposits includes both the Continental and Santa Rita deposits (Singer, 1986). The model indicates that the median tonnage of these deposits is 80 million tonnes. Ninety percent of the deposits contain 20 million tonnes or greater, and 10 percent contain 320 million tonnes or greater. The median copper grade is 0.98 percent Cu. Ninety percent of the deposits contain 0.51 percent Cu or greater, and 10 percent contain 1.9 percent Cu or greater. The median silver grade is 1 g/t Ag, and 10 percent of these deposits contain 12 g/t Ag. Ten percent of the deposits contain 0.022 percent Mo, and (or) 0.83 g/t Au.

Economic Significance

Porphyry copper deposits have been instrumental in keeping import reliance low (to about 6 percent). Richter and others (1986) estimate that the Silver City quadrangle has produced 3,805,000 tonnes Cu, has a reserve of 7,700,000 tonnes Cu, and has identified resources of 7,600,000 tonnes Cu; undiscovered resources are estimated to be in the millions of tonnes (n x 10^6) Cu. Porphyry copper, skarn-related deposits are very large, low-grade deposits that are mined using high volume, open-pit methods, where economies of scale make them economic.

PORPHYRY COPPER-MOLYBDENUM

Characteristics

Cox (1986) describes porphyry copper-molybdenum deposits as consisting of a stockwork of veinlets of quartz, chalcopyrite, and molybdenite in or near a porphyritic intrusion. The ratio of gold (in parts per million) to molybdenum (in percent) is less than 3. The deposits form in high-level intrusive porphyries that were formed contemporaneously with abundant dikes, faults, and breccia pipes; they may be located in the cupolas of batholiths. Ore is in the form of veinlets, disseminations, or massive replacements of favorable country rocks. Ore minerals are chalcopyrite, pyrite, and molybdenite. Peripheral veins or replacements may contain chalcopyrite, sphalerite, and galena and possibly gold. Outermost zones may have veins of c copper-silver-antimony sulfides, barite, and gold.

Richter and others (1986) identified the following criteria for discovering porphyry copper deposits in the Silver City quadrangle that can be used throughout the study area:

-- late Cretaceous-early Tertiary volcanic terranes intruded by cogenetic granodiorite-quartz monzonite porphyries
-- pronounced northeast- to east-northeast-trending fault-fracture-dike zones
-- potassic and phyllic hydrothermal alteration
-- copper vein deposits
-- broadly anomalous Pb, Zn, Ba, and Mn, ±Cu, Ag, and Sn in either magnetic or nonmagnetic fractions of panned stream sediments
-- locally anomalous Pb, Cu, Ba, Mn, Zn, Ag, ±Mo, Be, and Sn in magnetic fraction of panned stream sediments
-- pervasive propylitic alteration
-- late Cretaceous-early Tertiary volcanic terranes without known associated hypabyssal or plutonic rocks
-- base- and precious-metal vein deposits
-- covered or nonexposed plutonic rocks inferred from gravity or magnetic anomalies
-- northeast-trending zones of structural weakness inferred from gravity or magnetic features.

Richter and others (1986) determined that in the Silver City quadrangle several tracts were favorable for the occurrence of these deposits including the McGhee Peak, Granite Gap, Lordsburg, and Burro Mountains districts, and several districts north of Silver City. Estimated undiscovered resources in the Silver City quadrangle were million of tonnes Cu and tens to hundreds of thousands of tonnes of MoS_2 (Richter and others, 1986).

Grades and Tonnages

Porphyry copper-molybdenum deposits are mined in the same manner and are of similar size to other porphyry copper deposits. The grade-and-tonnage model for porphyry copper-molybdenum deposits includes the Tyrone deposit from the study area (**table 2-1**) (Singer and others, 1986) . The model indicates that the median tonnage for these deposits is 500 million tonnes. Ninety percent of the deposits contain 120 million tonnes or greater, and 10 percent contain 2,100 million tonnes or greater. The median copper grade is 0.42 percent Cu. Ninety percent of the deposits contain 0.26 percent Cu or greater, and 10 percent contain 0.69 percent Cu or greater. The median molybdenum grade is 0.016 percent Mo. Ninety percent of the deposits contain 0.0072 percent Mo or greater, and 10 percent contain 0.035 percent Mo or greater. The median silver grade is 1.2 g/t Ag. Ninety percent of the deposits contain 0.36 g/t Ag, and 10 percent of these deposits contain 4.2 g/t Ag. The median gold grade is 0.012 g/t Au. Ninety percent of the deposits contain 0.0036 g/t Au or greater, and 10 percent contain 0.043 g/t Au or greater.

Economic Significance

The U.S. is a net exporter of molybdenum (U.S. Bureau of Mines, 1994, p. 54); thus, porphyry copper-molybdenum deposits have been instrumental in keeping import reliance low. Sixty percent of the world's copper reserves and 99 percent of the world molybdenum reserves are contained in porphyry copper-type deposits (Kirkham and Sinclair, 1984a) like those near Silver City. The known porphyry copper-type deposits in the area contain very large copper and molybdenum resources.

PORPHYRY MOLYBDENUM, LOW FLUORINE

Characteristics

Porphyry molybdenum, low-fluorine deposits are fluorine-deficient stockwork molybdenum deposits that occur commonly in orogenic belts where calc-alkaline rocks have been intruded—a geologic environment similar to that of porphyry copper deposits. These deposits consist of a stockwork of quartz-molybdenite veinlets in felsic porphyry or the country rocks (Theodore, 1986). Ore is in veinlets and fractures; faulting is common. Primary minerals are molybdenite, pyrite, scheelite, and chalcopyrite; these may be present in the pluton, wallrocks, or where carbonate rocks are encountered as skarn. Potassium feldspar, biotite, calcite, muscovite, sericite, and clays may be gangue minerals. Where present, fluorine is generally less that 0.1 percent of the rock. Alteration assemblages are similar to those found in porphyry copper deposits, with potassic alteration in the center grading outward to propylitic alteration; both phyllic and argillic alteration may be overprinted. The volume of silica introduced as quartz in these deposits is generally much greater than in porphyry copper deposits. Cogenetic volcanic rocks also are missing in these deposits, suggesting that the deposits form in deeper geologic environments than do typical porphyry copper systems (Peterson and others, 1987).

Grades and Tonnages

The grade-and-tonnage model for porphyry molybdenum, low-fluorine deposits found that the median tonnage is 94 million tonnes of material (Menzie and Theodore, 1986). Ninety percent of the deposits contain 16 million tonnes or more, and 10 percent contain 560 million tonnes or more. The median grade of contained molybdenum (Mo) is 0.085 percent. Ninety percent of the deposits contain 0.055 percent or more Mo, and 10 percent contain 0.13 percent or more Mo. Some deposits may contain as much as 0.20 percent tungsten (Kirkham and Sinclair, 1984a).

Economic Significance

Porphyry molybdenum, low-fluorine deposits are a major source of molybdenum, which commonly occurs as a subsidiary metal sulfide in porphyry copper deposits. Of all types of molybdenum deposits in the United States in 1993, one Colorado mine produced molybdenum ore;

nine others in Arizona, California, Montana, New Mexico, and Utah recovered molybdenum as a byproduct. This country is currently a net exporter of molybdenum and has more than one-third of the world's identified resources. There are probably adequate supplies of molybdenum for the foreseeable future (U.S. Bureau of Mines, 1994, p. 117).

CARBONATE-HOSTED DEPOSITS

Carbonate-hosted deposits form where a hydrothermal system has transported acidic metal-bearing solutions into contact with carbonate rocks. In the study area, they are of three types -polymetallic replacements, southeast Missouri lead-zinc stratabound deposits, and skarns.

Polymetallic replacements are generally confined to zones where favorable strata are crossed by structural breaks or fissures. Hydrothermal solutions invade the carbonate rocks via the fissures, and sulfide minerals form from solution to replace the carbonate minerals. Some replacement bodies lie along veins, but irregular replacements may extend considerable distances away from the veins and into certain beds of carbonate wallrock.

Southeast Missouri lead-zinc deposits form at relatively low temperatures as open-space fillings in breccias and replacements, and skarns are massive deposits that form at higher temperatures through metamorphism of the carbonate host rocks. Skarn deposit types that occur, or may occur, in the study area are copper, gold-bearing, iron, zinc-lead, and tungsten skarns.

POLYMETALLIC REPLACEMENTS

Characteristics

These deposits are epigenetic manto (flat-lying, bedded) deposits that form as a result of hydrothermal activity in limestone, dolomite, and other soluble rocks near igneous intrusions. The carbonate rocks are replaced by solutions emanating from volcanic centers or shallow plutons. Morris (1986) reports that most of these deposits occur in mobile belts that have been subjected to moderate deformation and have been intruded by small plutons.

Geometry of these deposits is dependent on geologic structures. Tabular, pod-like, and pipe-like deposits, for example, may be localized by faults or fault intersections. Ribbon- or blanket-like deposits may be localized by bedding-plane faults, susceptible beds, or pre-existing solution channels. Polymetallic replacement deposits are commonly associated with, and sometimes appear to be fed by, polymetallic veins. Ore mineralogy consists of silver, lead, zinc, and copper minerals in massive lenses, pipes, and veins within the host rocks. Zonation of ore mineralogy is common. On a district-wide basis, the deposits commonly are zoned, from copper-rich in the central area grading outward to a wide lead-silver zone, and finally to a zinc- and manganese-rich outer zone. Locally, gold, arsenic, antimony, and bismuth may be abundant.

Criteria that may be indicative of areas favorable for the occurrence of these deposits are

(Richter and others, 1986):

-- the presence of favorable Paleozoic and Mesozoic carbonate host rocks intruded by Laramide and middle Tertiary felsic plutons dikes, or sills

-- the lack of calc-silicate minerals that would be indicative of skarn mineralization

-- the presence of sulfide minerals in limestone

-- complex northwest-trending fault zones

-- gravity or magnetic highs in pediment indicating a possible buried pluton adjacent to exposed calcareous rocks.

-- anomalous Bi, W, Mo, Pb, Cu, Au $\pm$ V, Be, F, and Nb in the nonmagnetic fraction of panned stream-sediment samples (Richter and others, 1986)

-- locally anomalous Pb, Cu, Ba, Mn, Zn, Ag $\pm$ Mo, Be, Sn, F in either or both the nonmagnetic or magnetic fraction of panned stream-sediment samples (Richter and others, 1986)

-- association with other replacement or skarn deposits.

In the Silver City quadrangle, areas in the Pinos Altos-Silver City area may contain undiscovered polymetallic replacement deposits (Richter and others, 1986). In the Douglas quadrangle, several areas have been identified as favorable for the occurrence of polymetallic replacement and associated deposit types (Hammarstrom and others, 1988). Assessment results in the Big Hatchet Mountains (Drewes and others, 1988) show an area with low potential for the occurrence of polymetallic replacement deposits, based on the nearly total absence of specific favorable signs of mineralization and a brief and fruitless mining history for production of copper lead, silver, and zinc from two small mines. In the Van Horn-El Paso quadrangles, an area encompassing the Tres Hermanas district was determined to be permissive for polymetallic replacements and associated deposit types (Johnson and others, 1988), and an area to the east and south of the Black Range Primitive Area was determined to be permissive for small polymetallic deposits occur. Similar deposits are likely to occur beneath the volcanic cover, according to Ericksen and others (1970).

Nickel-cobalt-silver-uranium (Ni-Co-Ag-U) veins that occur in the study area are a variation of polymetallic replacement deposits and have been described by numerous authors (Paige, 1916; Gillerman, 1964; Gillerman and Whitebread, 1956; Bastin, 1939; and Kissin, 1993). These deposits are restricted to a zone 2-km wide and 10-km long in the Black Hawk mining district in the Big Burro and Little Burro Mountains (Richter and others, 1986) where they occur as narrow fissure fillings along two intersecting fault systems. The 300-m-long and 3-m-wide veins are present chiefly in Precambrian quartz diorite gneiss on the side of a 72–

m.y.-old monzonite porphyry stock. Alteration chlorite gave a K-Ar date of 65 m.y. old (Gerwe and Norman, 1984). The ore consists of massive lenses and pods in sharp contact with gangue of calcite, dolomite, ankerite, siderite, rhodochrosite, barite, quartz, and pyrite. Primary ore minerals are native silver, argentite, niccolite (nickeline), millerite, skutterudite, nickel-skutterudite, sphalerite, bismuthinite, and pitchblende (uraninite) (Gillerman, 1964). Secondary ruby silver minerals (prousite and pyargyrite) and cerargyrite (chlorargryite) are locally abundant. Ore grades vary to as much as 86,000 g/t Ag, 8.9 percent Ni, 0.9 percent Co, 8.8 percent Zn, and .24 percent U_3O_8. Age-dating results suggest that mineralization is closely related to the monzonite porphyry stock. At this time (June, 1995), there are no descriptive or grade-and-tonnage models for nickel-cobalt-silver-uranium vein deposits. Criteria suggestive for the occurrence of deposits of this type in the Silver City quadrangle include (Richter and others, 1986):

-- skutterudite and nickel-skutterudite, the principal nickel-cobalt minerals, are associated locally with silver and pitchblende

-- the presence of Precambrian granite intruded by a Tertiary stock.

In the Silver City quadrangle, only a 2x10 km area of known deposits was delineated as favorable for the occurrence of these deposits (Richter and others, 1986). The distinctive suite of minerals that these deposits exhibit is not known elsewhere in the quadrangle. It is possible that some Ni and Co could be recovered in conjunction with Ag production, but the resource is probably negligible.

Grades and Tonnages

The grade-and-tonnage model for polymetallic replacement deposits has a median tonnage of 1.8 million metric tons (Mosier and others, 1986). Ninety percent of the deposits are 24,000 metric tons or greater, and 10 percent are 14 million metric tons or greater. Median metal grades are 5.2 percent Pb, 3.9 percent Zn, 0.094 percent Cu, 150 g/t Ag, and 0.19 g/t Au. Ninety percent of the deposits contain 1.2 percent Pb or greater, and 10 percent contain 21 percent Pb or greater; ninety percent contain 0.82 percent Zn or greater, and 10 percent contain 19 percent Zn or greater; 10 percent contain 0.87 percent Cu or greater; 10 percent of the deposits contain 690 g/t Ag or greater; and 10 percent of the deposits contain 4.4 g/t Au or greater. The deposit model was compiled using data from districts having at least 100,000 metric tons of combined resources and production. Small, isolated polymetallic replacements, like those in the Mimbres Resource Area that have been mined by individual miners, may be under-represented in the model, but are included in the polymetallic-vein model. There is no grade-tonnage model for Ni-Co-Ag-U vein deposits.

Economic Significance

Polymetallic replacements commonly produce copper, lead, zinc, and precious metals. In 1993, the U.S. had a net import reliance of 26 percent for zinc, 11 percent for lead, and 6 percent for copper (U.S. Bureau of Mines, 1994, p. 3, 54). Most examples of polymetallic replacement deposits in the study area do not fit the deposit model, but instead represent small, localized replacement vein deposits in contact with carbonate rock. Discovery of gold and silver in these polymetallic replacement deposits would enhance their development potential. However, the likelihood is low that deposits of this type could supply large quantities of metals.

The unusual mineralogy and presence of nickel and cobalt, two strategic materials, make the Ni-Co-Ag-U veins interesting. The U.S. has a net import reliance of 64 percent for nickel and 75 percent for cobalt, and most domestic resources are subeconomic for the foreseeable future (U.S. Bureau of Mines, 1994, p. 50-51, 118). Ni-Co-Ag-U veins occur worldwide. However, there are a few known deposits, such as Cobalt and Great Bear Lake in Canada and Joachimstahl in the former Czechoslovakia, which have nickel-cobalt-silver ore with uranium in carbonate gangue (Gillerman, 1964). There has been no reported production of Ni or Co from deposits in the study area; however, 40 tonnes of silver were mined from these deposits between 1881 and 1893.

RIO GRANDE RIFT LEAD-ZINC

Characteristics

The Rio Grande Rift lead-zinc deposit model is a new model developed specifically for this study because other models, including the southeast Missouri lead-zinc model [Mississippi Valley-type (MVT)], do not accurately describe the grades and tonnages of lead-zinc deposits found in southern New Mexico. Initial attempts at assessing the study area using the southeast Missouri lead-zinc deposit model yielded unrealistically high tonnages of materials, especially zinc.

The Rio Grande Rift lead-zinc deposit model is a subset of the southeast Missouri lead-zinc deposit type. The most productive district in the Rio Grande Rift lead-zinc model is Hansonburg, which is has been described as an MVT deposit (Roedder and others, 1968; Putnam and others 1983; Norman and others, 1985; and Cook and others, 1985). Mineralization like that at Hansonburg occurs sporadically along the entire length of the Rio Grande Rift in New Mexico (Putnam and others, 1983; McLemore and Barker, 1985; North and McLemore, 1986; McLemore and Leuth, 1995). Like its southeast Missouri counterpart, Rio Grande Rift lead-zinc deposits are stratabound, carbonate-hosted deposits of galena, sphalerite, and chalcopyrite in sedimentary rocks having primary and secondary porosity

commonly related to paleotopographic highs (Briskey, 1986). They are simply low-temperature, epigenetic, open-space fillings in carbonate rocks (Sangster, 1986).

Southeast Missouri lead-zinc deposits occur in platform carbonate successions. Often, they are located on the hinge line between a tectonically stable platform and a tectonically unstable basin. Host rocks are usually highly brecciated dolomite, but any porous rocks or open spaces may contain the deposits; examples include sandstone pinchouts, karst breccias, faults, permeable zones, slump, and fault breccias, and coarsely crystalline dolomite. Associated rocks are common sedimentary rocks, such as limestone, shale, sandstone, and evaporites. These deposits are not normally associated with igneous rocks. Mineralization occurs in early diagenesis, or in some cases long after lithification of the host rocks, when low-temperature (80° C-150° C) metals-bearing brines originating in sedimentary basins adjacent to platform carbonate rocks migrate into the carbonates and precipitate ore minerals (Sangster, 1984). Alteration of carbonate rock adjacent to the deposits is typically not present. Open-space filling and replacement mineralization commonly occur at the interface between gray and tan dolomite or in traps wherever permeable rocks abut impermeable ones, such as at carbonate-shale and limestone-dolomite facies changes. Galena, sphalerite, and chalcopyrite are the main ore minerals; pyrite, marcasite, dolomite, calcite, and lesser amounts of quartz, barite, and fluorite may be gangue. In order of abundance, minor siegenite, bornite, tennantite, bravoite, digenite, covellite, arsenopyrite, fletcherite, adularia, pyrrhotite, magnetite, millerite, polydymite, vaesite, djurleite, chalcocite, anilite, and enargite may be present (Briskey, 1986).

At Hansonburg, Permian arkosic units are thought to be the source of lead, which originated in Precambrian granitic rocks (Putnam and others, 1983). Sulfur is supplied by Permian evaporites (Allmandinger (1974). Galena, fluorite, barite, and quartz with minor sphalerite, pyrite, and chalcopyrite are the main hydrothermal minerals. Conodonts in the host rocks show progressive change recording a thermal anomaly up to 0.4 km away from the deposits (Cook and others, 1985). Genetic association with the Rio Grande Rift has not been established.

Grades and tonnages

The grade and tonnage model for Rio Grande Rift lead-zinc deposits consists of production data from three lead-zinc-producing districts outside of the study area in the northern San Andres Mountains of Sierra County. These districts are Hansonburg, Mockingbird Gap, and Salinas Peak. Of the three districts, the Hansonburg district had the largest production (almost 210,000 metric tons of mineralized material) and the Salinas Peak

district had the smallest (481 metric tons of mineralized material).

Using the three deposits in the model, Rio Grande Rift lead-zinc deposits contain much smaller tonnages and have much higher lead and lower zinc grades and than do southeast Missouri lead-zinc deposits. The mean tonnage of deposits in the model is less than 70,000 metric tons, which is a quite small compared to the median of 35 million metric tons for southeast Missouri lead-zinc deposits (combined with Appalachian lead-zinc deposits) (Mosier and Briskey, 1986).

Metal grades for Rio Grande Rift lead-zinc deposits range up to almost 0.009 percent Cu, up to 0.065 g/t Au, from 2.7 to 19.9 g/t Ag, 2.4 to 6.9 percent Pb, and up to 0.94 percent Zn. In contrast, median metal grades for southeast Missouri lead-zinc deposits are 0.48 g/t Ag, 0.87 percent Pb, and 4 percent Zn. This confirms that Rio Grande Rift lead-zinc deposits are generally more lead rich and have much less zinc than southeast Missouri lead-zinc deposits. They also may contain byproduct copper, gold, and silver.

Economic significance

In this and other countries, southeast Missouri lead-zinc deposits are a major source of the world's lead and zinc. Rio Grande Rift lead-zinc deposits, however, being a subset of that deposit type consisting of much smaller deposits, are of economic significance on a local or regional scale.

REPLACEMENT MANGANESE

Characteristics

A number of replacement manganese deposits in the study area consist of manganese oxide minerals occurring in epigenetic veins or cavity fillings in limestone, dolomite, marble, or associated sedimentary rocks. Veins or cavity fillings may be associated with granite or granodiorite in intrusive complexes. Mosier (1986) notes that rhodochrosite and rhodonite are the primary manganese-bearing ore minerals. These may weather to psilomelane, pyrolusite, and wad, comprising the richest part of most deposits. Pyrite, chalcopyrite, galena, and sphalerite may be accessory sulfide minerals. Calcite, manganocalcite, quartz, barite, fluorite, and jasper are gangue. Replacement manganese deposits north of Silver City may contain significant recoverable silver. Factors that control ore formation are permeability of the carbonate host rocks—often an impermeable shale formation will act as an upper trap to help concentrate mineralization—and the proximity of the intrusive contact.

Richter and others (1986) determined that in the Silver City quadrangle, favorable conditions for the occurrence of replacement manganese deposits are:

-- the presence of Paleozoic carbonate host rocks above the present water table

-- nearby intrusive complexes
-- geochemical anomalies for manganese
-- north– to northeast-trending faults, fractures, and dikes.

In the Douglas quadrangle, Hammarstrom and others (1988) outlined several favorable areas for the occurrence of replacement manganese and associated deposit types. They include Rincon and Gillespie districts, an area south of Granite Gap, and a large area stretching from north of the Eureka district southward to the Mexico border, including the Apache No. 2 and Fremont districts to the east. In the El Paso-Van Horn quadrangles, Johnson and others (1988) considered the Tres Hermanas area favorable for the occurrence of several deposit types, including replacement manganese deposits.

Grades and Tonnages

The grade-and-tonnage model for replacement manganese deposits (Mosier, 1986b) shows that they are relatively small, having a median tonnage of 22,000 tonnes. Ninety percent of the deposits contain 940 tonnes or greater, while 10 percent contain 530,000 tonnes or greater. The median grade for replacement manganese deposits is 36 percent Mn. Ninety percent of the deposits contain 16 percent Mn or greater, and 10 percent contain 46 percent Mn or greater. Ten percent of the deposits of this type contain 0.53 percent Cu or greater. The presence of silver is not accounted for in the model.

Economic Significance

The U.S. has a net import reliance of 100 percent for manganese. It is considered a strategic material by this country and is part of the National Defense Stockpile. U.S. identified resources are insignificant.

To stimulate domestic production during World War II, a manganese-purchasing depot was established in Deming and small manganese deposits in the study area were actively mined. From 1951 to 1955, the manganese-purchasing depot was re-opened. Richter and others (1986) estimate that manganese production in the Silver City quadrangle was 3,422 tonnes; no estimate of identified or undiscovered Mn resources was attempted. Manganese/iron production was estimated to have been 2,000,000 tonnes with a reserve of 10,000,000 tonnes; both identified resources and undiscovered resources were estimated to be millions of tonnes Mn and Fe.

Replacement manganese deposits in the area are typically small deposits that could be reactivated during times of national crisis and fill domestic needs for manganese over a short period. On the open market, however, these deposits are too small and of too low grade to compete with deposits in Gabon, South Africa, Brazil, Australia, and Mexico, for example.

SKARN DEPOSITS

Skarn deposits are the world's number one source of tungsten, a major source of copper, important sources of iron, molybdenum, and zinc, and minor sources of beryllium, bismuth, boron, cobalt, gold, lead, silver, and tin (Einaudi and others, 1981). They may also serve as sources of industrial minerals, such as fluorite, graphite, and talc. Skarn deposits have been recognized as a distinct class of mineral deposits for more than 100 years, and have become increasingly important as sources of certain metals (Burt, 1982). They are hosted in limestone, dolomite, and other calcareous sedimentary rocks that have been intruded by mafic to felsic plutons. They form by interaction of carbonate and aluminosilicate rocks and magmatic hydrothermal solutions. Skarn deposits exist in a broad range of geologic environments, and range in age from Precambrian to late Tertiary. Most economic skarn deposits are relatively young, and are related to hydrothermal activity associated with dioritic or granitic plutonism in orogenic belts (Einaudi and Burt, 1982). The feature that distinguishes skarn deposits from other types of mineral deposits is the presence of calc-silicate contact metamorphic gangue minerals that form at relatively high temperature, such as garnet, diopside, epidote, and actinolite.

In the Mimbres Resource Area, four classes of skarn deposits—copper, iron, tungsten, and zinc-lead, with some overlap—have been identified on the basis of the dominant economic metal. Gold-bearing skarn deposits (those skarn deposits having one or more grams of gold per tonne of ore) have not been identified in the area, but they are known to occur in areas with other skarn deposit types and precious-metal production. Likewise, tin skarn deposits have not been identified in the study area, but the assessment in the Silver City area (Richter and others, 1986) determined that parts of the area is permissive for their occurrence. Known skarn deposits are typically middle- to late-stage calcic-types associated with rocks that range from granitoid to alkali composition. In the following text, the characteristics of each type of skarn deposit are discussed, and grades and tonnages from the deposit models are listed.

TUNGSTEN SKARN DEPOSITS

Characteristics

Tungsten skarn deposits form at the contact between various roof pendants and batholithic rocks and in widespread thermal aureoles of apical zones of the pluton at the contact between the felsic intrusive stock and surrounding carbonate country rock (Reed and Cox, 1986). Tungsten skarn deposits are generally associated with calc-alkaline intrusives; the plutons are typically coarse-grained (potassium feldspar megacryst) porphyritic granodiorite to quartz monzonite stocks and batholiths. Plutons associated with tungsten skarn deposits are

probably emplaced at greater depths than porphyry copper-related plutons (Einaudi and others, 1981). Tungsten skarn deposits also are emplaced in a generally deeper, higher temperature, and more reduced environment than copper or zinc-lead skarn deposits (Dawson, 1984). Tungsten, associated metals, and sulfur in these deposits may be derived from both the pluton and from the host rocks by the magmatic-hydrothermal fluid, convecting groundwater, formation water, or combinations of all three. Principal ore mineral in a tungsten skarn deposit is scheelite; sulfide minerals may be associated. Calc-silicate minerals, such as andradite garnet and tremolite, calcite, dolomite, quartz, and biotite are common gangue minerals. Lesser amounts of vesuvianite, fluorite, and native bismuth may be present.

Criteria for locating tungsten skarn deposits in the study area are:

-- presence of Paleozoic limestones and felsic plutonic rocks
-- presence of Pennsylvanian and Permian limestones
-- northwest-trending major fault zones
-- andradite, tremolite, and other calc-silicate skarn assemblage minerals
-- gravity/magnetic highs in pediment, indicative of a possible buried pluton adjacent to exposed calcareous rocks.

In the Silver City assessment (Richter and others, 1986), a restricted area within Paleozoic limestone in the metamorphic aureole of the Granite Gap stock was determined to be favorable for the occurrence of small tungsten skarn deposits.

Grades and Tonnages

Menzie and Jones (1986) report that tungsten skarn deposits have a median tonnage of about 1.1 million tonnes. Ninety percent of these deposits have 50,000 tonnes or more, and 10 percent have 22 million tonnes or more. Tungsten skarn deposits have a median grade of 0.67 percent WO_3. Ninety percent of the grades are 0.34 percent WO_3 or greater, and 10 percent are 1.4 percent WO_3 or greater.

Economic Significance

Tungsten skarn deposits are the world's primary source of tungsten. Although the U.S. imports 84 percent of its tungsten (U.S. Bureau of Mines, 1994, p. 3) and considers it a strategic material, there is an overabundance of tungsten on the world's markets. Large quantities of low-price tungsten are available from China, Bolivia, and Peru.

COPPER SKARN DEPOSITS

Characteristics

Copper skarn deposits form from magmatic hydrothermal replacement of sedimentary carbonate deposits, such as limestone and dolostone, or metavolcanic or metaintrusive rocks.

According to Kirkham and Sinclair (1984b), most copper skarn deposits occur in mobile belts in or near limestone deposits at or near the contacts with mafic to felsic intrusives. The majority of copper skarn deposits are associated with calc-alkaline granodiorite to quartz monzonite stocks emplaced in continental margin orogenic belts. They may have a spatial relationship with porphyry copper deposits, other skarn deposits, or replacement deposits. Some of the world's largest copper skarn deposits are associated with porphyry copper deposits and are located in southwestern North America (Einaudi and others, 1981). These large copper skarn deposits rarely occur more than a few hundred meters from the associated intrusions in porphyry copper districts. Ore minerals are chalcopyrite, pyrite, hematite, magnetite, bornite, and pyrrhotite. Molybdenite, bismuthinite, sphalerite, galena, and other sulfide minerals may be present. Gold and silver may be important products (Cox and Theodore, 1986). Associated non-ore minerals are calcite, dolomite, quartz, andradite-grossularite, diopside-hedenbergite, epidote, actinolite, tremolite, chlorite, wollastonite, serpentine, potassium feldspar, talc, and biotite. Weathering may produce copper carbonates and silicates and iron-rich silicates.

Richter and others (1986) identified several criteria for discovering copper skarn deposits in the Silver City quadrangle that can be used throughout the study area:

-- upper Cretaceous to lower Tertiary intermediate to felsic stocks intruding Paleozoic carbonate rocks

-- calc-silicate minerals and (or) magnetite in country rocks

-- scheelite, garnet, and diopside in stream sediment concentrates

-- anomalous Bi, W, Mo, Pb, Cu, Ag, $\pm$ Au, V, Be, and Nb in the nonmagnetic fraction of paned stream sediments

-- broadly anomalous Pb, Zn, Ba, Mn, $\pm$ Cu, Ag, Sn and Mo in the magnetic fraction of panned stream sediments

-- locally anomalous Pb, Cu, Ba, Mn, Zn, Ag, $\pm$ Mo, Be, Sn and fluorite in the either (or both) fractions of panned stream sediments

-- spatial relationship with porphyry copper deposits, other skarn deposits, and (or) replacement deposits

-- gravity or magnetic highs in pediment indicative of a possible buried pluton adjacent to exposed calcareous rocks.

Areas of exposed carbonate rocks outside of the areas of igneous activity should be judged to have no potential for copper skarn deposits, because they are beyond the thermal or chemical influence of the igneous system.

Richter and others (1986) determined that parts of the porphyry copper area north of Silver City were favorable for the occurrence of copper skarn deposits. In the Douglas quadrangle, several areas were delineated as being favorable for the occurrence of copper skarn deposits and associated deposit types (Hammarstrom and others, (1988). They included areas around the Rincon and Gillespie mining districts, an area south of Granite Gap, and a large area stretching from north of the Eureka district southward to the border with Mexico, including the Apache No. 2 and Fremont districts to the east. In the Van Horn-El Paso quadrangles, an area surrounding the Tres Hermanas mining district was outlined as favorable for the occurrence of copper skarn deposits and associated deposit types (Johnson and others, 1988).

Grades and Tonnages

Some copper skarn deposits are large and high-grade deposits containing significant amounts of copper, silver, and gold. The grade-and-tonnage model of copper skarn deposits (Jones and Menzie, 1986) has a median tonnage of 560,000 tonnes. Ninety percent of the deposits are 34,000 tonnes or greater, and 10 percent are 9.2 million tonnes or greater. The median copper grade is 1.7 percent Cu. Ninety percent of the deposits have grades of 0.7 percent Cu or greater, and 10 percent have grades of 4.0 percent or greater. More than 20 percent of the copper skarn deposits in the model reported gold and silver grades. Ten percent of the deposits have 36 g/t Ag and (or) 2.8 g/t Au or greater.

Economic Significance

Copper skarn deposits in the study area have been important producers in the past and, at present, the Continental mine is the most important copper skarn deposit in southwestern New Mexico. In the Silver City quadrangle, Richter and others (1986) estimate that copper production from all types of skarn deposits was 520,000 tonnes Cu. Copper reserves and identified resources in skarn deposits of all types were 500,000 tonnes and n x 10^5 (hundreds of thousands) tonnes, respectively. Although the area has large porphyry copper deposits, discovery of additional of copper skarn deposits would have a positive impact on the local economy.

ZINC-LEAD SKARN DEPOSITS

Characteristics

Zinc-lead skarn deposits form at the contacts of felsic to intermediate intrusive and calcareous sedimentary rocks or along structural paths in unmetamorphosed rocks at some distance from the intrusives (Dawson and Sangster, 1984). Intrusive rocks may range from granodiorite to granite and diorite to syenite; quartz monzonite may be the most common

intrusive associated with these deposits. Sedimentary host rocks are carbonate rocks (both pure and impure limestone) and calcareous pelites, or regionally metamorphosed equivalents. Zinc, lead, and associated metals may be derived from both the plutonic rocks and the country rocks by a magmatic hydrothermal system, consisting of convecting groundwater, formational water, or a combination of the two. Chemical mechanisms, like fluoride and chloride complexing, affect metal transport. Metal deposition is mainly controlled by the reaction of ore fluid with carbonate host rock.

Sphalerite and galena are the chief ore minerals; sphalerite is the more abundant. Other ore minerals may be pyrrhotite, pyrite, magnetite, chalcopyrite, bornite, arsenopyrite, scheelite, bismuthinite, stannite, and fluorite. Gold and silver may be present, but do not form distinct minerals (Cox, 1986d). Gangue minerals may be garnet, manganoan hedenbergite, diopside, epidote, ilvaite, chlorite, rhodonite, fluorite, calcite, and quartz.

Richter and others (1986) identified several criteria for locating zinc-lead skarn deposits in the Silver City quadrangle that can be used throughout the study area:

-- upper Cretaceous to lower Tertiary stocks intruding Paleozoic carbonate rocks

-- calc-silicate minerals and (or) magnetite in country rocks

-- scheelite, garnet, and diopside in stream sediment concentrates

-- anomalous Bi, W, Mo, Pb, Cu, Ag, $\pm$ Au, V, Be, and Nb in the nonmagnetic fraction of panned stream sediments

-- broadly anomalous Pb, Zn, Ba, Mn, $\pm$ Cu, Ag, Sn and Mo in the magnetic fraction of panned stream sediments

-- locally anomalous Pb, Cu, Ba, Mn, Zn, Ag, $\pm$ Mo, Be, Sn and fluorite in the either (or both) fractions of panned stream sediments

-- spatial relationship with porphyry copper deposits, other skarn deposits, and (or) replacement deposits

-- gravity or magnetic highs in pediment indicative of a possible buried pluton adjacent to exposed calcareous rocks.

Areas of exposed carbonate rocks outside of the areas of igneous activity should be judged to have no potential for zinc-lead skarn deposits, because they are beyond the thermal or chemical influence of the igneous system.

In the Silver City quadrangle, Richter and others (1986) outlined several areas that are favorable for the occurrence of zinc-lead skarn deposits, most north of Silver City. Another area includes the area around the White Signal mining district. Total zinc and lead resources in deposits of this type were estimated to be hundreds of thousands tonnes zinc and tens of

thousands tonnes lead (Richter and others, 1986). In the Douglas quadrangle, areas delineated by Hammarstrom and others (1988) as favorable for the occurrence of copper skarn deposits are favorable also for zinc-lead skarn deposits. In the Van Horn-El Paso quadrangles, an area surrounding the Tres Hermanas mining district was outlined as being favorable for the occurrence of zinc-lead skarn deposits and associated deposit types (Johnson and others, 1988).

Grades and Tonnages

The grade-and-tonnage model of zinc-lead skarn deposits (Mosier, 1986c) has a median tonnage of 1.4 million metric tons. Ninety percent of the deposits are 16,000 metric tons or greater, and 10 percent are 12 million metric tons or greater. Median metal grades are 2.8 percent Pb, 5.9 percent Zn, 0.09 percent Cu, and 58 g/t Ag. Ninety percent of the deposits contain .87 percent Pb or greater, and 10 percent contain 7.6 percent Pb or greater; 90 percent contain 2.7 percent Zn or greater, and 10 percent contain 13 percent Zn or greater; 10 percent contain 1.3 percent Cu or greater; 10 percent of the deposits contain 290 g/t Ag or greater; and 10 percent of the deposits contain .46 g/t Au or greater.

Economic Significance

Zinc-lead skarn deposits commonly produce lead, zinc, copper, and precious metals. In 1993, the United States had a net import reliance of 26 percent for zinc, 11 percent for lead, and 6 percent for copper (U.S. Bureau of Mines, 1994, p. 3, 54). These deposits may be of substantial grade and moderate tonnage and have been a past source of relatively large amounts of metals from the study area. However, there is no local lead-zinc smelter; thus, small- to medium-size identified deposits may not be mined owing to transportation costs.

IRON SKARN DEPOSITS

Characteristics

Iron skarn deposits form at the contact of intrusive rocks and carbonate or calcareous rocks. They are created by the hydrothermal metasomatic replacement of calcareous wall rocks contemporaneous with intrusion of the igneous rocks. Intrusive rocks may be gabbro, diorite, diabase, syenite, tonalite, granodiorite, granite, and coeval volcanic rocks (Cox, 1986e). Carbonate rock localizes precipitates of magnetite and other iron-rich minerals, probably as a reaction to an increase in the pH of the ore fluids (Gross, 1984). Principal ore minerals may be magnetite, hematite, martite, and chalcopyrite, with associated pyrite and pyrrhotite. Apatite, calc-silicate skarn minerals, calcite, and dolomite are gangue minerals. Some of the deposits are gold-bearing. Iron skarn deposits usually are located at or near the contact with intrusive rock, and may be discovered by their strong geophysical magnetic anomaly or by the presence

of abundant magnetite in exposures and float.

Richter and others (1986) identified several criteria for locating iron skarn deposits in the Silver City quadrangle. These criteria can be used throughout the study area. They include:

-- favorable Paleozoic carbonate host rocks intruded by Laramide stocks

-- calc-silicate minerals and (or) magnetite in country rocks

-- strong positive aeromagnetic anomalies

-- northeast-trending fracture-fault zones

-- calc-silicate alteration

-- spatial relationship with porphyry copper deposits, other skarn deposits, and (or) replacement deposits

-- gravity or magnetic highs in pediment indicative of a possible buried pluton adjacent to exposed calcareous rock. Areas of exposed carbonate rock outside of the areas of igneous activity should be judged to have no potential for iron skarn deposits, because they are beyond the thermal or chemical influence of the igneous system.

In the Silver City quadrangle, several areas north of Silver City outlined by Richter and others (1986) are favorable for the occurrence of both copper and zinc-lead and iron skarn deposits. Richter and others (1986) report, however, that the probability of finding new near-surface deposits is not encouraging. Undiscovered iron skarn deposits are likely to be deep, and not amenable to mining unless substantial amounts of copper and zinc are present. Iron reserves are unknown; identified resources are estimated to be tens of millions of tonnes. In the Van Horn-El Paso quadrangles, an area surrounding the Tres Hermanas mining district was outlined as favorable for the occurrence of iron skarn deposits and associated types (Johnson and others, 1988).

Grades and Tonnages

The grade-and-tonnage model for iron skarn deposits (Mosier and Menzie, 1986a) shows a median tonnage of 7.2 million tonnes and a median grade of 50 percent Fe. Ninety percent of the iron skarn deposits contain 330,000 tonnes or greater, and 10 percent contain 160 million tonnes or greater. Ninety percent of these deposits contain 36 percent Fe or greater and 10 percent contain 63 percent Fe or greater.

Economic Significance

In 1993, the U.S. had a net import reliance of 12 percent for iron ore, with imports mainly from Canada, Brazil, and Venezuela. U.S. iron-ore resources are estimated at about 110 billion tonnes of ore, mainly in low-grade taconite from the Lake Superior district that

requires beneficiation and agglomeration to be used commercially. Skarn deposits are an important source of iron ore; iron skarn deposits of as much as 1 billion tonnes are known. Within the Silver City quadrangle, Richter and others (1986), estimate that all types of skarn deposits, including iron skarn deposits, had produced 7,100,000 tonnes of iron.

GOLD-BEARING SKARN DEPOSITS

Characteristics

Gold-bearing skarn deposits have an average grade of 1 g/t Au or greater, and have been (or could be) exploited primarily for gold (Orris and others, 1987). They conform to the characteristics of other skarn deposit types, in that they are hosted in a wide variety of sedimentary and igneous rocks, including limestone, dolomite, shale, conglomerate, rhyolitic to andesite tuff, and granitoid. Gold-bearing skarn deposits are hosted in rocks with a pre-metamorphic calcareous component; these are intruded by felsic to intermediate plutons, dikes, sills, or stocks that are not necessarily porphyritic. The high value of gold relative to more abundant metals such as copper, iron, lead, and zinc, has resulted in some deposits being classified as gold-bearing skarn deposits. Additionally, some skarn deposits mined primarily for other metals, but having a gold content of 1 g/t or greater, are thought of as byproduct-gold skarn deposits, a subset of gold-bearing skarn deposits.

In North America, gold-bearing skarn deposits exist mostly on the continental margin in Cordilleran and island-arc settings, but may also occur in the rifted craton, where the rift controls the hydrothermal system that forms the gold-bearing deposit. Orris and others (1987) note that cratonic gold-bearing skarn deposits are much less abundant than those that form on the continental margin. Metallic minerals present in these deposits include native gold, electrum, pyrite, chalcopyrite, pyrrhotite, arsenopyrite, sphalerite, and galena. Bismuthinite, native bismuth, and other bismuth minerals may be present, as may magnetite and hematite. Gold, silver, nickel, and lead tellurides occur, as do bornite, loellingite, and tungsten- and molybdenite-bearing minerals. Skarn-type calc-silicate minerals are gangue. Orris and others (1987) suggest in the deposit model that, in areas zoned from proximal base-metal deposits to distal precious-metal deposits, all sites within the precious-metals zone favorable for the formation of skarn deposits should be considered as permissive for hosting gold-bearing skarn deposits. Furthermore, polymetallic veins that have geochemical signatures and sulfide mineral occurrences similar to those of many gold-bearing skarn deposits may be surface indicators of a buried gold-bearing skarn deposit. A local magnetic high resulting from an increased abundance of pyrrhotite and magnetite may be a geophysical expression of gold-bearing skarn deposit.

In the Douglas 1° x 2° quadrangle, several areas were cited as being favorable for the occurrence of gold-bearing skarn deposits and associated deposit types (Hammarstrom and others, 1988). They include the Rincon and Gillespie districts, an area south of Granite Gap, and a large area stretching from north of Eureka district southward to the Mexico border, including the Apache No. 2 and Fremont districts to the east.

Grades and Tonnages

The grade-and-tonnage model for gold-bearing skarn deposits (Orris and others, 1987) has a median size of 400,000 tonnes. Ninety percent of the deposits are about 15,000 tonnes or greater, and 10 percent of the deposits are 15 million tonnes or greater. The median grade is 5 g/t Au. Ninety percent of the deposits have a grade of about 1.5 g/t Au or greater, and 10 percent have about 20 g/t Au or greater. By definition, they contain a minimum of 1 g/t Au. Copper, silver, lead, zinc, and iron may also occur in significant concentrations.

Economic Significance

The United States is the world's second largest gold-producing nation after South Africa, and is a net exporter of gold. This country has about 12 percent of the world's identified gold resources. In the early 1980s, significant effort was directed on discovery of gold skarn deposits; almost 8 tonnes of gold per year can be produced from some deposits. As of 1987, deposits of this type had produced over 930 tonnes of gold (Orris and others, 1987, p. 5).

HYDROTHERMAL VEIN DEPOSITS

Hydrothermal deposits form as a result of precipitation of metals from migrating solutions. Metal-bearing solutions acquired metals within or near a magma source and migrated to sites where part or all of the metals precipitated. Heat necessary to drive hydrothermal circulation may be provided by thermal convection from a cooling intrusion, by magmatic volatiles venting from an intrusion, or by radioactive decay (Cathles, 1981). Fluids migrate to sites of precipitation along faults and fractures; precipitation along these openings in the rocks form hydrothermal vein deposits. Four types of hydrothermal veins are present in the study area—polymetallic veins, gold-silver-tellurium veins associated with alkalic rocks, epigenetic barite veins, and tungsten veins.

POLYMETALLIC VEINS

Characteristics

Polymetallic veins are quartz-carbonate veins where gold and silver are associated with base-metal sulfides related to hypabyssal intrusions in sedimentary and metamorphic terranes (Cox, 1986f). Sangster (1984) reports that polymetallic veins form as hydrothermal open-space fillings in areas with high permeability, most commonly in discordant, narrow,

elongate, and steeply-dipping zones such as intrusive contacts, fault intersections, and breccia veins and pipes. There may be some offset of the wall rocks. Ore is usually confined to the vein; wall-rock replacement and disseminations are uncommon, but may occur.

Gold, silver and the base metals copper, lead, and zinc, are the chief economic commodities of polymetallic veins. Not all of these metals are present in every deposit, and the concentration of individual metals may vary greatly from deposit to deposit.
Base-metal-bearing minerals such as galena, sphalerite, and chalcopyrite are most common in these deposits, but gold and silver are the most prized metals. Native gold and electrum are common sources of gold, and silver is contained in galena, distinct minerals such native silver, argentite, and freibergite, or as various sulfosalt minerals, most commonly tetrahedrite (Sangster, 1984).

Richter and others (1986) identify several criteria for locating polymetallic veins and replacements in the Silver City quadrangle that can be used throughout the study area:

-- favorable Paleozoic carbonate host rocks intruded by Laramide and middle Tertiary felsic plutons

-- favorable Paleozoic and Mesozoic carbonate host rocks intruded by middle Tertiary felsic dikes, sills, and plutons

-- presence of complex northwest-trending fault zones

-- anomalous Bi, W, Mo, Pb, Cu, Au, V, Be, F, and Nb in the nonmagnetic fraction of panned stream-sediment samples

-- locally anomalous Pb, Cu, Ba, Mn, Zn, Ag, Mo, Be, Sn, F in either or both the nonmagnetic or magnetic fraction of panned stream-sediment samples.

Using these criteria, Richter and others (1986) identify an area around the Lordsburg district favorable for polymetallic veins associated with porphyry copper deposits. Other areas delineated for veins as sources of base metals are in the Burro Mountains, central Peloncillo Mountains, Steeple Rock area, and areas north of Silver City. Hammarstrom and others (1988) identified several areas in the Douglas 1° x 2° quadrangle that are favorable for polymetallic veins and associated deposit types. Ericksen and others (1970) report that small polymetallic deposits occur just east and south of the Black Range Primitive Area, and that similar deposits are likely to occur beneath volcanic cover.

Grades and Tonnages

The grade-and-tonnage model of polymetallic veins (Bliss and Cox, 1986) has a median tonnage of 7,600 tonnes. Ninety percent of the deposits are 290 tonnes or greater, and 10 percent are 200,000 tonnes or greater. Median metal grades are 9.0 percent Pb, 2.1 percent

Zn, 820 g/t Ag, and 0.13 g/t Au. Ninety percent of the deposits contain 2.4 percent Pb or greater, and 10 percent contain 33 percent Pb or greater; 10 percent contain 7.6 percent Zn or greater; 10 percent contain 0.89 percent Cu or greater; 10 percent contain 690 g/t Ag or greater; ninety percent contain 4,700 g/t Ag or greater, and 10 percent contain 11 g/t Au or greater.

Economic Significance

Polymetallic veins commonly produce copper, lead, zinc, and precious metals. In 1993, the United States had a net import reliance of 26 percent for zinc, 11 percent for lead, and 6 percent for copper (U.S. Bureau of Mines, 1994, p. 3, 54). Lead and zinc are produced in quantity from large replacement deposits in the mid-continent region. A major change in price or demand for these commodities would be necessary for the successful operation of small mines, although the presence of gold and silver as byproducts would certainly enhance the possibility of development. Where no local lead-zinc smelter is present, small identified polymetallic-vein deposits would not be mined, owing to transportation costs. Veins in the area are generally small but may be rich; production is likely to have only local impact.

GOLD-SILVER-TELLURIUM VEINS ASSOCIATED WITH ALKALIC ROCKS

Characteristics

Gold-silver-tellurium veins associated with alkalic rocks (hereafter called Au-Ag-Te veins), as the name suggests, consist of gold-telluride minerals and fluorite in veins and breccia bodies related to hypabyssal or extrusive alkalic rocks, such as syenite, monzonite, diorite, phonolite, monchiquite, and vogesite (Cox and Bagby, 1986a). Au-Ag-Te veins occur where the disrupted Precambrian craton is covered with a thin layer of Phanerozoic rocks and in areas of extensive fracturing, faulting, or jointing. In New Mexico, deposits of this type have been identified in rocks associated with the Rio Grande Rift. Ore deposition is controlled by fractures and the presence of small intrusions near major structural breaks. Propylitic alteration is common, dominated by carbonates (particularly dolomite) and pyrite (Cox and Bagby, 1986a).

In addition to veins and breccias, this deposit type may include replacement and disseminated mineralization (Bliss and others, 1992). Deposits with disseminated mineralization may be amenable to bulk mining methods and could be considered porphyry gold deposits (Thorpe and Franklin, 1984). Replacement bodies may form where veins cut limestone.

Gold is the primary commodity in deposits of this type. Native gold and gold telluride minerals such as calaverite, sylvanite, hessite, and coloradoite are the chief ore minerals. Fine-grained pyrite, galena, sphalerite, tetrahedrite, and stilbite are accessory minerals. Smoky

quartz, calcite, purple fluorite, barite, celestite, roscoelite, and adularia are gangue (Cox and Bagby, 1986a). Telluride minerals are not specifically reported in some deposits, as they are destroyed by weathering and often not recognized. Deposits are often oxidized and primary telluride and sulfide mineralization may be poorly preserved or missing. Because of the very fine grain size, the "flour" gold the telluride minerals release may not be concentrated in placer deposits. Bliss and others (1992) found a ratio of Au-Ag-Te veins with placers to those without placers to be about 6 to 1. Some tellurium weathered from telluride minerals may be redeposited as green oxides. Geochemical anomalies for Au, Ag, Te, Cu, Pb, Zn, Sb, Hg, F, Ba, and platinum-group elements may assist in finding deposits of this type (Cox and Bagby, 1986).

Hammarstrom and others (1988) recognized potential for these deposits in several areas of the Douglas quadrangle, including the Rincon and Gillespie districts, an area south of Granite Gap, and a large area stretching from north of the Eureka district southward to the Mexico border and including the Apache No. 2 and Fremont districts to the east. The only suspected occurrences of this type in the Douglas quadrangle, however, are in the Sylvanite district in the Little Hatchet Mountains.

Grades and Tonnages

The grade-and-tonnage model for Au-Ag-Te veins (Bliss and others, 1992) has a median tonnage of 2 million tonnes and median gold and silver grades of 6.6 g/t and 3.4 g/t, respectively. Ninety percent of the deposits contain 83,000 tonnes or greater, and 10 percent contain 50 million tonnes or greater. Ninety percent of the deposits contain 1.2 g/t Au or greater, and 10 percent contain 37 g/t Au or greater. Ten percent of the deposits contain 79 g/t Ag or greater.

Economic Significance

Deposits of this type may be of moderate tonnage and relatively low grade. Often, they may be mined by high-tonnage, open-pit methods that take advantage of economies of scale and modern heap-leaching technologies. Adjacent placers are a modest source of additional gold. The median amount of gold expected from placering associated with Au-Ag-Te veins is 0.2 tonnes; the maximum amount of contained gold from such placering is about 3.0 tonnes (Bliss and others, 1992).

EPIGENETIC BARITE VEINS

Characteristics

Epigenetic barite veins consist of barite along faults, fractures, or shear zones in rocks of any type (Clark and Orris, 1991). The veins range in width from a few centimeters to tens

of meters; lengths range from tens of meters to greater than one kilometer. Ore minerals are barite, fluorite, galena, sphalerite, chalcopyrite, rare-earth minerals, gold, and silver in varying amounts. Gangue minerals include quartz, pyrite, iron oxides, clays, and many of those minerals listed above as ore minerals that are not of economic grade. In the veins, barite is fine to coarse grained, crystalline or cataclastic, and typically white or light gray. The hardness of barite is approximately equal to calcite, a little lower than fluorite, and lower than quartz. Barite is resistant to weathering; its high density helps distinguish barite from other minerals. Because it is commonly intergrown with calcite and fluorite, whole-rock specimens may have lower densities than pure barite. High iron-oxide content is a detriment to many barite applications.

Grades and Tonnages

The grade-and-tonnage model (Orris, 1992) has a median tonnage of epigenetic barite veins of 110,000 tonnes; the median grade is 91 percent barite. Ninety percent of the deposits contain 4,000 tonnes or greater, and 10 percent contain 2.8 million tonnes or greater. Ninety percent of the deposits have a grade of 60 percent barite, and 10 percent have a grade of 98 percent or greater barite.

Economic Significance

In 1994, the U.S. had a net import reliance for barite of 82 percent (U.S. Bureau of Mines, 1995, p. 4). Major foreign sources are China, India, and Mexico. Epigenetic barite veins contain relatively small tonnages of barite, so it takes several of these deposits to fill worldwide demand.

TUNGSTEN VEINS

Characteristics

Tungsten vein deposits consist of quartz veins and quartz-rich pegmatites with segregations, pods, and disseminations of wolframite or scheelite mineralization and molybdenite and base-metal sulfides as accessory minerals. The mineral deposit model (Cox and Bagby, 1986b) describes tungsten vein deposits as occurring in belts of granitic plutons derived from remelting of continental crust. Veins form in tensional fractures in the granitic plutons and their wallrocks, in sedimentary rocks such as shale and sandstone, and in the metamorphic equivalents of sedimentary rocks in contact with plutons. Wolframite is the main tungsten mineral of economic importance. Scheelite is often present in minor amounts, but is of economic importance in some deposits. Other minerals present include molybdenite, bismuthinite, pyrite, pyrrhotite, arsenopyrite, bornite, chalcopyrite, cassiterite, beryl, and fluorite. Tungsten veins may be located by heavy-mineral analysis, since wolframite persists

in soils and in fluvial deposits. Mineral occurrences that are interpreted as tungsten vein deposits occur in several mining districts in Grant and Hidalgo Counties.

Some important criteria for locating tungsten veins in the Silver City quadrangle (Richter and others, 1986) are:

-- felsic plutonic rocks

-- Precambrian terrane (pegmatites are generally associated with xenoliths of hornblende gneiss and amphibolite in Precambrian granite)

-- scheelite; commonly found with epidote and locally with molybdenite, pyrite, chalcopyrite, wolframite, and Bi minerals

-- sericite-pyrite and calcite-pyrite alteration zones

-- well–developed joint system, allowing penetration by hydrothermal fluids

-- geochemical anomalies for Be, Pb, Zn, and Cu

-- magnetic or gravity lows due to pyritic alteration and silicic nature of the pluton.

Several areas in the quadrangle, including Granite Gap, Gold Hill, Victorio, and Bound Ranch mining districts, and districts in the Burro Mountains, were outlined by Richter and others (1986) as favorable for the occurrence of tungsten veins, replacements, and pegmatites.

Grades and Tonnages

The grade-and-tonnage model of tungsten veins is for vein systems rather than individual veins. The model (Jones and Menzie, 1986b) has a median tonnage of 560,000 tonnes. Ninety percent of the deposits contain 45,000 tonnes or greater, and 10 percent contain 7 million tonnes or greater. The median grade of these deposits is 0.91 percent WO_3. Ninety percent of these deposits contain 0.6 percent WO_3 or greater, and 10 percent contain 1.4 percent WO_3 or greater. Individual tungsten vein ore bodies in the Silver City quadrangle were estimated by Richter and others (1986) to contain no more than a few hundred tonnes of ore at grades of less than 2 percent WO_3.

Economic Significance

Although the U.S. imports 84 percent of its tungsten (U.S. Bureau of Mines, 1994, p. 3) and considers it a strategic mineral, there is an over abundance of tungsten on the world market. Large quantities of low-price tungsten are available from China, Bolivia, and Peru. Tungsten veins in the study area could be exploited as small, high-cost operations in times of shortage.

VOLCANOGENIC MASSIVE SULFIDE DEPOSITS

Volcanogenic massive sulfide (VMS) deposits are predominantly stratiform accumulations of sulfide minerals that form on or near the sea floor by precipitation near sites from which hydrothermal fluids were being discharged (Franklin and others, 1981). The enclosing strata consist of prominent amounts of volcanic rock, but the ore may be contained in the sedimentary rock that makes up the sea floor. These deposits consist of more than 60 percent sulfide—mostly pyrite and (or) pyrrhotite with variable amounts of sphalerite, chalcopyrite, and galena. Metals in these deposits are derived from the underlying rocks through which the hydrothermal fluids must pass. Fluids, whether of magmatic or recirculated seawater, leach metals from the rocks and redeposit them in stratiform layers. Underlying magmas provide the heat source to drive the hydrothermal system, as well as providing some metals. Seawater may provide sulfur and a small quantity of metals. Economic VMS deposits of massive copper-zinc-lead sulfides have been recognized around the world in rocks ranging in age from Archean to Miocene. In North America, however, Precambrian rocks contain more than 65 percent of the deposits of this type (Sangster and Scott, 1976); they are the most important class of Proterozoic ore deposits found in the southwestern U.S. VMS deposits tend to form in clusters 15-30 km across (Sangster, 1972) and are confined to very specific volcanic or metavolcanic terranes.

Various classifications for VMS deposits have been proposed (Franklin and others, 1981). The classification adopted here is the one used for the descriptive deposit models (Cox and Singer, 1986), which is based primarily on the depositional characteristics of the deposits, (i.e., host-rock lithology and geologic environment). Three VMS deposit types are recognized --Besshi, Cyprus, and Kuroko.

BESSHI MASSIVE SULFIDE

Characteristics

Besshi massive sulfide deposits are stratiform, base-metal rich accumulations of volcanogenic massive sulfides associated with submarine basalt of intra-plate or oceanic origin (Fox, 1984). They usually are enclosed in thinly laminated, continentally derived, clastic sediments along with the mafic volcanic rocks. Locally, black shale and red chert may be present. The deposits are thin, sheet-like tabular bodies that, when strongly deformed, become pencil-shaped. They may be laterally extensive and tend to cluster in en echelon pattern (Cos, 1986g). Carbonate rocks that may be indicative of exhalative deposition are invariably present in Besshi massive sulfide deposits.

The ore may be massive, banded, or in veins. Pyrite, pyrrhotite, and chalcopyrite are the main ore constituents, with minor sphalerite, magnetite, galena, valleriite, bornite, cobaltite, tetrahedrite, and hematite. Stannite and (or) molybdenite are often minor constituents of these deposits. Quartz, carbonate, albite, mica, chlorite, amphibole, and tourmaline are gangue minerals. Actinolite and serpentine that may represent metamorphosed mafic rocks are often present. Besshi-type deposits often have lower base-metal and precious-metal grades than do other type of volcanogenic massive sulfide deposits. However, they may contain anomalously high, and occasionally economic, levels of cobalt (Fox, 1984).

Besshi massive sulfide deposits form, along with thick sequences of continentally derived clastic sediment, in epicontinental (shallow)-rifting environments as a result of hydrothermal convection in underlying mafic volcaniclastic sedimentary rocks (Fox, 1984). Thick, terriginous turbidite sediments are evidence of a rapid rate of crustal extension in an immature epicontinental rift. Fox (1984) suggests that there is no genetic relationship between Kuroko-type and Besshi-type mineralization. He concludes that Besshi-type deposits occupy a middle ground in a rift-related spectrum of deposits that include sediment-hosted lead-zinc ores at one end and Cyprus-type copper-zinc ores at the other. Besshi massive sulfide deposits are not confined to any particular part of the world or any particular geological epoch. They are found in Japan, Norway, the U.S., and other parts of the world in rocks dating from the Precambrian and younger. Modern submarine hydrothermal discharges analogous to Besshi-type deposits have been discovered recently along spreading center, such as at Guaymas basin in the Gulf of California, where the Colorado River is rapidly depositing terriginous sediment (Fox, 1984).

Grades and Tonnages

The grade-and-tonnage model of Besshi massive sulfide deposits (Singer, 1986b) includes only deposits that contain at least 10,000 tonnes of ore. The model has a median tonnage of 220,000 metric tons. Ninety percent of the deposits are 12,000 metric tons or greater, and 10 percent are 3.8 million metric tons or greater. Median copper grade is 1.5 percent Cu. Ninety percent contain 0.64 percent Cu or greater, and 10 percent contain 3.3 percent Cu or greater. Ten percent contain 0.4 percent Zn or greater; the same percentage contain 9.5 g/t Ag or greater and (or) 0.76 g/t Au or greater.

Economic Significance

Solomon (1976) estimates that at least a third of the world's known economic base-metal deposits are hosted in mafic extrusive rocks, or by sedimentary rock sequences that contain a significant mafic volcanic component. In many mineralized belts, Besshi massive

sulfide deposits are the predominant volcanogenic deposit type, constituting an important base-metal resource worldwide (Fox, 1984).

CYPRUS MASSIVE SULFIDE

Characteristics

Cyprus massive sulfide deposits consist of massive pyrite, chalcopyrite, and sphalerite in successions of pillow lavas deposited on or below the seafloor from solutions discharged from high temperature submarine hydrothermal systems. Rarely, ore is localized in the sediments overlying the pillow lavas. Mineralization occurs in submarine hot springs along axial grabens in oceanic or back-arc spreading ridges and in hot springs related to submarine volcanoes producing seamounts. On rare occasions, fossil worm tubes indicative of hot springs environments are preserved. Franklin and others (1981) describe the deposits as occurring in the volcanic part of ophiolites (a sequence of rocks associated with spreading centers, with volcanic rocks constituting the uppermost part) and being characterized by pyrite and chalcopyrite as the predominant sulfide minerals, with minor sphalerite in both massive ore and a stockwork zone. The prototypical deposits occur in the Troodos ophiolite massif of Cyprus, but examples are known in several other parts of the world including Canada, Guatemala, the Philippines, and Turkey. These deposit typically form in clusters; a good guide is the presence of other Cyprus-type deposits.

Typical deposits consist of massive ore in as many as three zones—an ochre horizon capping the massive ore, the massive zone itself, and a basal siliceous ore zone. These ore zones are underlain by a sulfide stockwork or stringer zone that extends for hundreds of meters below the deposit. The ochre horizon is a manganese-poor, iron-rich sedimentary cap to the massive ore, and consists of brown and orange-yellow massive-to-layered sediment containing goethite and quartz with some illite and jarosite and corroded fragments of pyrite (Franklin and others, 1981). Red hematite may be present. Ochre horizons that occur in many deposits, but are not always present, range from a few centimeters to five meters thick. Massive ore consists of porous, colliform-banded blocks of pyrite and marcasite; ore may be conglomeratic or massive siliceous. Sulfides may be brecciated and recemented. Massive siliceous ore generally consists of chalcopyrite in a quartz matrix; in some bodies, sphalerite is more common than chalcopyrite. The stringer or stockwork zone consists of two types of ore: (1) sulfide and quartz-sulfide veins, which contain some chalcopyrite and sphalerite that cement basaltic breccia and fill fractures in pillow lavas; or (2) disseminated sulfides that impregnate altered lavas (Franklin and others, 1981). Disseminated sulfides are uniformly pyrite. Minor amounts of cobalt, gold, and silver may be present in the stringer zone. Alteration in that zone

results in feldspar destruction; quartz, chalcedony, and chlorite are abundant (Singer, 1986).

Grades and Tonnages

The grade-and-tonnage model (Singer and Mosier, 1986) has a the median tonnage of 1,600,000 tonnes. Ninety percent of the deposits are 100,000 metric tons or greater, and 10 percent are 17 million metric tons or greater. The median copper grade is 1.7 percent Cu. Ninety percent contain 0.63 percent Cu or greater, and 10 percent of the deposits contain 3.9 percent Cu or greater. Ten percent of these deposits contain 2.1 percent Zn or greater; the same percentage contains 33 g/t Ag or greater. Ten percent of the deposits contain 1.9 g/t Au or greater.

Economic Significance

Deposits are generally small; however, one mining district may contain several ore bodies, and their numbers may be cumulative. For example during 1977-78, 28 percent of the Cu, 41 percent of the Zn, 39 percent of the Ag, and 7.5 percent of the Au produced in Canada was from Cyprus massive sulfide deposits (Lydon and others, 1984).

KUROKO MASSIVE SULFIDE

Characteristics

Kuroko massive-sulfide deposits are polymetallic volcanogenic-massive sulfide deposits that form in an island arc setting, deposited by hot springs related to submarine volcanism, probably under anoxic marine conditions (Singer, 1986c). They develop near centers of felsic volcanism, near the more felsic top of a submarine volcano or volcanic-sedimentary sequence. Hosts are marine rhyolite, dacite, and subordinate basalt and associated sediment, such as organic-rich mudstone or shale. The deposits may be brecciated locally or located near felsic domes. Some deposits have been transported by gravitaty into depressions in the seafloor, where the slumped and redeposited ore may exhibit graded bedding. Lead-rich deposits are associated with abundant, fine-grained volcanogenic sediment. Kuroko massive-sulfide deposits are usually zoned. The upper stratiform massive ore zone (or black ore zone) consists of pyrite, sphalerite, and chalcopyrite. Pyrrhotite, galena, barite, tetrahedrite, bornite, and quartz may be present in significant amounts. The lower stratiform zone (or yellow ore zone) consists mainly of pyrite, chalcopyrite, and quartz, but pyrrhotite and magnetite may be significant accessory minerals. The stockwork (or stringer) zone consists of pyrite and chalcopyrite and associated gold and silver values. Silica, chlorite, and sericite alteration may be abundant. Deposits may be blanketed with a zone of chert, felsite, and pyrite, and possibly zeolite, clay (montmorillonite and chlorite), carbonate minerals, and hematite. Graphitic schist may be present.

Grades and Tonnages

The grade-and-tonnage model of Kuroko massive-sulfide deposits (Singer and Mosier, 1986) has a median tonnage of 1.5 million metric tons. Ninety percent of the deposits are 120,000 metric tons or greater, and 10 percent are 18 million metric tons or greater. Median metal grades are 2.0 percent Zn, 1.3 percent Cu, 0.16 g/t Au, 13 g/t Ag. Ten percent of these deposits contain 1.9 percent Pb or greater; 10 percent contain 8.7 percent Zn or greater. Ninety percent of these deposits contain 0.45 percent Cu or greater, and 10 percent contain 3.5 percent Cu or greater. Ten percent of the deposits contain 100 g/t Ag or greater; and 10 percent of the deposits contain 2.3 g/t Au or greater.

One of the deposits in the grade-and-tonnage model for this deposit type is Pecos mine in the Pecos mining district, San Miguel and Santa Fe Counties, New Mexico. From 1927 to early 1939, the Pecos mine was New Mexico's largest producer of base and precious metals. Minor scheelite is associated with sheared volcanogenic sulfides at the mine (Fulp, 1987). During its lifetime, the mine yielded 2.3 million tons of ore that formed from 1,710 m.y. old submarine volcanism.

Economic Significance

In 1993, the U.S. had a net import reliance of 26 percent for zinc, 11 percent for lead, and 6 percent for copper (U.S. Bureau of Mines, 1994, p. 3, 54). Kuroko massive sulfide deposits are relatively small in tonnage, but may be rich in base and precious metals. In Canada, for example, in 1977-78, Kuroko massive sulfide deposits accounted for 27 percent of the lead, 22 percent of the zinc, 2.5 percent of the copper, and 19 percent of the silver production (Lydon and others, 1984). Examples of these deposits occur in the Rio Grande Rift north of the study area.

EPITHERMAL DEPOSITS

Epithermal deposit types occur in the western part of the study area in Tertiary volcanic rocks that range in composition from andesite to rhyolite. They probably formed in fossil equivalents of high-temperature geothermal systems like those seen in some active geothermal systems today (White, 1981). These deposits are volcanic-centered, the magmatic heat providing the energy that drives the system. Epithermal fluids were dominated by local meteoric water, although a small portion of magmatic water may have been present in some epithermal systems. These deposits may be rich in precious and base metals. Epithermal deposits in the study area are epithermal manganese, quartz-adularia and quartz-alunite gold-silver veins, and sediment-hosted gold deposits.

EPITHERMAL MANGANESE

Characteristics

Epithermal manganese deposits form when manganese mineralization is deposited in epithermal veins filling faults and fractures in subaerially exposed volcanic flows, tuffs, breccias, and agglomerates (Mosier, 1986d). Composition of the volcanic host rocks may be rhyolite, dacite, andesite, or basalt. Primary mineralogy may be rhodochrosite, manganocalcite, quartz, chalcedony, barite, and zeolites, but oxidation of the primary ore zone may produce the manganese oxides psilomelane, pyrolusite, braunite, wad, manganite, cryptomelane, hollandite, and coronadite, and iron oxides (Mosier, 1986d). Gangue may consist chiefly of calcite (locally manganiferous), quartz, and chalcedony; opal, travertine, fluorite, and gypsum may occur locally.

Richter and others (1986) found that in the Silver City quadrangle, epithermal manganese deposits are commonly found in middle to upper Tertiary volcanic and volcaniclastic rocks cut by known Basin-and-Range faults. The faults may lie beneath shallow cover, as indicated by magnetic or gravity measurements. Calcite veins and black calcite are common, and there may be local evidence for hot springs. Geochemical anomalies for Pb, Zn, Ba, Mn, $\pm$ Ca, Ag, Sn, and Mo in the magnetic fraction of panned stream sediments may be suggestive of epithermal manganese mineralization.

Areas in the central Peloncillo Mountains, Pyramid Mountains, and north of the Burro Mountains, were delineated as being favorable for the occurrence of these deposits (Richter and others, 1986). They denote that the probability of finding additional small deposits. In the Douglas quadrangle, the Silvertip, Apache No. 2, the Antelope Wells-Dog Mountains, and Fremont mining districts, part of the central Peloncillo Mountains south of Granite Gap, and the Animas Mountains from the southern tip of the Rincon district southward to the New Mexico-Mexico border, were determined to be permissive for epithermal manganese and associated mineral deposit types. An area between the Tres Hermanas district and the Potrillo Mountains district in the Van Horn-El Paso quadrangles was designated favorable for the occurrence of epithermal manganese and associated deposit types (Johnson and others, 1988).

Grades and Tonnages

The grade-and-tonnage model for epithermal manganese deposits (Mosier, 1986e) shows that these deposits are generally small. Their median tonnage is 25,000 tonnes and their median grade is 30 percent Mn. Ninety percent of the deposits have tonnages of 2,400 tonnes or greater, and 10 percent have tonnages of 260,000 tonnes or greater. Ninety percent of the

deposits have grades of 20 percent Mn or greater, while 10 percent of the deposits have grades of 42 percent Mn or greater.

Economic Significance

The U.S. has a net import reliance of 100 percent for manganese. It is considered a strategic material by this country and is part of the National Defense Stockpile. U.S. identified resources are insignificant. To stimulate domestic production during World War II, a manganese-purchasing depot was established in Deming and small epithermal manganese deposits in the study area were actively mined. From 1951 to 1955, the manganese-purchasing depot was re-opened. Epithermal manganese deposits in the study are typically small deposits that could be activated during times of national crisis and could help fill domestic needs for manganese over a short period. In the Silver City quadrangle, identified resources were estimated to be thousands of tonnes of manganese, and undiscovered resources were in the thousands of tonnes (Richter and others, 1986). On the open market, these deposits are too small and of too low grade to compete with deposits in Australia, Brazil, Gabon, Mexico, South Africa, and other countries.

VOLCANIC-HOSTED EPITHERMAL GOLD-SILVER

The presence of large areas of volcanic rock offers the potential for occurrence of several types of epithermal gold-silver deposits. Early-on, Nolan (1933) and Lindgren (1933) recognized some of the characteristics of epithermal deposits and proposed divisions of deposit types. Over the last several decades, several different schemes for classifying deposits of this type have been discussed (John and others, 1993). These schemes were based on criteria such as volcanic-tectonic setting, wallrock alteration, ore mineralogy, nature of the basement rocks, and fluid chemistry (e.g., Buchanan, 1981; Berger and Eimon, 1983; Sillitoe and Bonham, 1984; Hayba and others, 1985; Nelson and Giles, 1985; Mosier and others, 1986; Heald and others, 1987; Berger and Henley, 1989; and White and Hedenquist, 1990.)

The classification scheme of Cox and Singer (1986) is used here, with modification, to allow for the characteristics of the study area. Epithermal gold-silver deposits are divided into two major types: quartz-adularia gold (also called Comstock, Creede, and Sado epithermal, low sulfidation, or adularia-sericite) and quartz-alunite (also known as acid-sulfate, alunite-kaolinite $\pm$ pyrophyllite, or high sulfidation). For quartz-adularia type deposits, the scheme divides the quartz-adularia type deposits into Comstock, Creede, and Sado deposits based on the nature of the basement rocks beneath the volcanic pile. Comstock deposits occur over basement rocks composed of clastic sedimentary rocks and their metamorphic equivalents—these geothermal systems lack access to saline fluids from basement sources

(Mosier and others, 1986a). Creede deposits, on the other hand, are polymetallic metallic deposits related to sources of saline fluids in prevolcanic basement rocks (Mosier and others, 1986b). Sado deposits overlie basement rocks composed of thick older volcanic sequences or igneous rocks (Mosier and others, 1986c). Comstock and Sado deposits have lower base-metal grades than do Creede deposits. For this reason, this study uses only Comstock and Sado deposit grades and tonnages in the epithermal quartz-adularia deposit model. Hot-spring gold deposits probably represent surficial expressions of quartz-adularia or quartz-alunite systems.

Quartz-Adularia Gold-Silver Vein Deposits

Characteristics

Quartz-adularia gold-silver vein deposits are volcanic-hosted gold-silver deposits of the acid-sulfate type that form as a result of epithermal fluids migrating along through-going, anastomosing fracture systems, major normal faults and fractures related to doming, and ring-fracture zones and joints associated with calderas. Host rocks may be andesite, dacite, quartz latite, rhyodacite, or rhyolite. Mineralization is related to calc-alkaline or bimodal volcanism (Mosier, Singer, and Berger, 1986).

The variety of basement rocks that these deposit pass through leads to different ore mineralogies. Ore in Comstock deposits consists of argentite, gold, or electrum. There may be silver sulfosalts and (or) naumannite. Galena, sphalerite, chalcopyrite, tellurides, hematite, and arsenopyrite are moderate to sparse. Creede deposits are richest in base metals, commonly including galena, sphalerite, chalcopyrite, and copper and silver sulfosalts. In Sado deposits, the ore consists of gold with argentite, electrum, and chalcopyrite. Sulfosalts and tellurides are moderate, and galena and sphalerite are sparse.

Grades and Tonnages

The grade-and-tonnage model for epithermal quartz-adularia gold deposits, which combine the data for Comstock and Sado deposits, found the median tonnage for these deposits to be about 610,000 tonnes. Ninety percent of the deposits contain about 80,000 tonnes or more and 10 percent of the deposits contain about 8.8 million tonnes or more. The grade-and-tonnage model found the median gold grade of in these deposits to be about 7.2 g/t Au; 90 percent of the deposits contain 2.0 g/t Au or more and 10 percent contain 26 g/t Au or more. Median silver grade is 105 g/t Ag; 90 percent of the deposits contain 7.0 g/t Ag or more and 10 percent contain 750 g/t Ag or more.

Economic Significance

Epithermal quartz-adularia gold deposits are a productive type of metalliferous mineral

deposit. From 1859 to 1957, the world-famous Comstock Lode deposit in Nevada produced more than 8.25 million troy ounces of gold from about 19 million tons of ore from its underground mine (John and others, 1993; and Bonham, 1969). The Rawhide deposit in Nevada (an example that is currently mined using modern open-pit methods) went into production in 1989, and has estimated reserves of 59.3 million tons of ore containing 17.5 million troy ounces of silver and 1.62 million troy ounces of gold (John and others, 1993; and Black and others, 1991). Deposits of this type have been instrumental in the U.S. becoming the second-leading gold-producing nation in the world.

Quartz-Alunite Gold-Silver Veins

Characteristics

Epithermal quartz-alunite gold-silver deposits are found associated with major volcanic sequences, especially those dominated by intermediate calc-alkalic volcanic rocks. According to Ashley (1982), these deposits are most common in island arc and back-arc spreading centers, but may occur in any of the several tectonic settings where calc-alkalic volcanic rock occurs. Host rocks for these deposits are usually intermediate porphyritic volcanic rock types, most commonly rhyodacite; trachyandesite, quartz latite, rhyolite, and volcanic clastic sequences may also be hosts. Mineralization may be in the form of veins, breccia pipes, pods, or dikes. Breccia pipes may form by hydrofracturing resulting from silica deposition, choked conduits, and boiling. Replacement vein deposits are often porous and vuggy, with comb structure and crustified banding. Associated hydrothermal alteration is predominantly argillic. Quartz-montmorillonite is the most common assemblage, quartz-kaolinite, quartz-kaolinite-potassic mica, and quartz-mixed layer illite-montmorillonite are other common assemblages (Ashley, 1982). Ore bodies are always located in or adjacent to advanced argillic zones.

The ore mineralogy is commonly various sulfosalt mineralogies, including enargite-luzonite series minerals, tetrahedrite-tennantite series minerals, and silver sulfosalts. Pyrite is ubiquitous. Bismuthinite, native gold, and telluride minerals may be present. Chalcopyrite may be common as a minor constituent. Galena, sphalerite and wurtzite are minor. These minerals may be present at the outer edges of productive areas, suggesting a district-wide zoning of base metals.

Epithermal quartz-alunite gold veins are always associated with acid-sulfate hydrothermal alteration and may occur in acid-sulfate altered areas above and peripheral to porphyry copper deposits in several major porphyry copper provinces of the world. Therefore, these deposits are not only a potentially significant source of gold, silver, and

copper, but they may be shallow-level indicators of deeper porphyry systems.

Grades and Tonnages

The grade-and-tonnage model for epithermal quartz-alunite gold deposits (Mosier and Menzie, 1986b) shows that the median tonnage for these deposits is 1.6 million tonnes. Ninety percent of the deposits contain 22,000 tonnes or more and 10 percent of the deposits contain 11 million tonnes or more. The grade-and-tonnage model found the median gold grade in these deposits is 8.4 g/t Au; 90 percent of the deposits contain 3.9 g/t Au or more and 10 percent contain 18 g/t Au or more. The median silver grade is 18 g/t Ag; 90 percent of the deposits contain 2.4 g/t Ag or more and 10 percent contain 130 g/t Ag or more. The median copper grade is 0.05 percent Cu; 10 percent contain 5.0 percent Cu or more.

Economic Significance

These deposit may contain substantial amounts of precious metals, especially gold. The deposit are amenable to open-pit mining, high-volume mining methods, and heap-leaching --processes that keep the cost of mining low. These mining techniques allow low-grade deposits to be mined economically.

SEDIMENT-HOSTED GOLD

Characteristics

Sediment-hosted gold deposits (variously termed "Carlin-type" deposits for the Carlin, Nev., deposit where they are exploited, or "invisible-gold" deposits for the extremely fine grain size of the gold they contain) consist of very fine-grained gold and sulfides disseminated in carbonaceous calcareous rocks, siliceous shale, and other noncarbonate host rocks. Thinly bedded silty or argillaceous carbonaceous limestone or dolomite with carbonaceous shale was thought to be the primary host rocks for these deposits, but deposits in siliceous shale and other noncarbonate rocks have been discovered recently. Associated igneous rocks are felsic to intermediate intrusions, and are usually Mesozoic or Tertiary in age --plutons that may promote epithermal activity. Felsic dikes or sills are part of many deposits; in some deposits the intrusions have been altered and form part of the ore. The deposits are characterized by several types of primary alteration including silicification, calcification, argillization, and carbonization. Silicification forms jasperoids, which are silica-rich epigenetic replacements of chert, carbonate, and siliceous siltstone, that are mineralized along with the host rocks. Carbonization introduces organic carbon in the form of amorphous organic matter or cryptocrystalline graphite, where gold is localized by adsorption and (or) reduction (Leventhal and others, 1987). Ore mineralogy consists of native gold, pyrite, realgar, orpiment, arsenopyrite, cinnabar, fluorite, barite, and stibnite. Highest concentrations of gold can occur

where fluorine is plentiful. Exposed ore zones do not form placers. Geochemical detection and discrimination of gold-dominant systems such as these is more difficult than with base-metal-rich deposits (Nash, 1994); trace elements include gold, silver, arsenic, mercury, thallium, and antimony with low base-metal content.

These deposits may have been formed beneath fossil geothermal systems. The deposits form at depths of about 1,000 m or more below the paleosurface (Bonham, 1985). Research at the Jerritt Canyon, Nev., deposit determined that the disseminated nature and small grain size of the gold, and the alteration zonation, mineralogy, and geochemistry observed at many deposits of this type, can be explained by a combination of fluid mixing, simultaneous cooling, dilution and oxidation of the ore fluid, and wallrock reaction, with sulfidation of reactive iron in the host rocks (Hofstra and others, 1991). Northrop and others (1987) note that three hydrologic events occurred—regional metamorphism, hydrothermal gold mineralization, and hydrothermal post-gold mineralization. Gold mineralization followed Tertiary faulting, and resulted from mixing of gold-bearing brines with dilute meteoric water at a depth of about 1-3 km. Gold in solution was deposited along with arsenic, antimony, and mercury as a function of fluid mixing as the system went from brine to dilute meteoric water. In fact, the Jerritt Canyon sediment-hosted gold deposit was explored as an antimony anomaly before its gold potential was recognized.

Hammarstrom and others (1988) propose that the geologic setting of part of the study area is similar to the central and northern Great Basin in Nevada and Utah where sediment-hosted gold deposits are commonly found. They designate much of the Douglas quadrangle in New Mexico favorable for the occurrence of sediment-hosted (Carlin-type) gold deposits. The report cites several features in the study area that are favorable for the occurrence of these deposits:

-- presence of silty carbonaceous carbonate host rocks and multi-stage, complex jasperoids associated with oxidized, argillically altered sedimentary rocks
-- abundant iron oxide
-- thrust and high-angle faults
-- presence of intrusions, dikes and sills of felsic to intermediate composition
-- anomalous gold, silver, and barite values.

Hammarstrom and others (1988) identified the Amanacer prospect in northern Chihuahua, Mexico (southeast of the border between Hidalgo and Luna Counties in the Sierra Rica) as a sediment-hosted gold deposit. At that prospect, the host rock is moderate- to thin-bedded limestone of U-Bar Formation. The prospect consists of jasperoid, jasperoid breccia,

and carbonaceous limestone having anomalous Au, Ag, As, Sb, Hg, and Ba. The presence of a sediment-hosted gold deposit in proximity to similar rocks in the study area indicates potential for occurrence of sediment-hosted gold deposits.

Grades and Tonnages

A revised grade-and-tonnage model (Mosier and others, 1992) supersedes the previous model (Bagby and others, 1986) and reflects the discovery of many deposits of this type in noncarbonate host rocks. Some silver-rich deposits have been reassigned to the distal disseminated silver-gold deposit type. The revised model has a median tonnage of 6.6 million tonnes. Ninety percent of the deposits contain 920,000 tonnes or greater, and 10 percent contain 48 million tonnes or greater. The median grade of deposits of this type is 2.3 g/t Au. Ninety percent of the deposits contain 0.96 g/t Au or greater, and 10 percent contain 5.6 g/t Au or greater. Three of the 39 deposits in the model contain silver ranging from 0.7 to 3.4 g/t. These deposits are of moderate tonnage and low grade. Normally, these are high-tonnage, low-grade deposits that are mined by open-pit methods to take advantage of the economies of scale. Grades as low as 2 g/t Au and 75 g/t Ag can be mined economically.

Economic Significance

The relatively ordinary appearance of the oxidized sedimentary host rocks prevented earlier discovery of sediment-hosted gold deposits. Since 1979, the high price of gold and the discovery of the Carlin deposit have made bulk-minable precious-metal deposits such as these important sources of gold. The Carlin deposit, the most famous of the type, was discovered in 1961-62. Although several deposits of this type had been discovered prior to 1961, it was the discovery of the large Carlin deposit that focused attention on this deposit type. By 1993, deposits of this type in California and Nevada helped to make the U.S. the world's second-leading gold producer after South Africa.

OTHER DEPOSIT TYPES

Other deposit types include those that do not fall into a neat category or grouping. Rhyolite-hosted tin deposits are of igneous volcanic origin, but form through automineralization (see below) of tin carried in a vapor in the rhyolite. The remainder of the deposit types are those that are unrelated to igneous processes; i.e., their genesis bears no apparent or direct relation to igneous activity. Geologic environments for these deposits types can often be specified with a great degree of precision, because, although not strictly syngenetic, they formed as a result of geologic processes occurring throughout broad regions of the Earth's crust—processes that may leave clues in the rocks. Thus, on a regional basis, it is relatively easy to define permissive environments for these classes of deposits. Deposits

included in this type are gold placers, oolitic ironstone, marine-evaporite gypsum, lacustrine gypsum, and sediment-hosted copper.

RHYOLITE-HOSTED TIN

Characteristics

Low-grade, low-tonnage deposits of rhyolite-hosted tin type are found in Mexico and New Mexico (Huspeni and others, 1984; Foshag and Fries, 1942; Fries, 1940). They are described in the deposit model as consisting of cassiterite and wood tin [a variety of cassiterite having a concentric structure of radiating fibers resembling wood (American Geological Institute, 1977)] in discontinuous veinlets in rhyolite flow-dome complexes and derivative placers (Reed and others, 1986). Host rocks are generally metaluminous to slightly peraluminous rhyolite or latite (where the molecular proportion of aluminum oxide is greater than that of sodium oxide and potassium oxide). Rhyolites are characteristically alkali-feldspar rhyolites or topaz rhyolites, with SiO_2 being greater than 75 percent. Distinctive accessory minerals in rhyolite may include topaz, fluorite, bixbyite, pseudobrookite, and beryl. Deposits are generally in the fractured and brecciated outer parts of flow-dome complexes where permeability is high. Tin skarn deposits may be associated with rhyolite-hosted tin deposits, and small tin placers may occur in adjacent streams.

Rhyolite-hosted tin deposits form through automineralization, a process wherein the source of the mineralization and the site of deposition are within the veined lava itself (Duffield and others, 1990). Mineralization occurs in newly emplaced lava as it cools and devitrifies; vapor from the lava carries tin that is redeposited as cassiterite in the outer rind of the cooling lava. Cassiterite occurs in 10 mm- to 10 cm-wide discontinuous veins and veinlets; vein dimensions seldom exceed 75 m. Specularite may form as crusts on cavity walls, in which case cassiterite may be intermixed with specularite. Cassiterite may also occur as disseminations in the matrix of rhyolite flows or fault breccias. Alteration may be present or absent. Based on the geochemical similarity of associated magmas, Reed and others (1986) speculate that rhyolite-hosted tin deposits may be a surface expression of Climax molybdenum deposits.

Important criteria for locating rhyolite-hosted tin deposits are:

-- Tertiary high-K eruptive centers and epizonal intrusives

-- anomalous cassiterite in heavy mineral concentrates from streams draining middle Tertiary eruptive centers

-- Sn-rich variants of the stockwork Mo deposits

-- specularite as crusts on cavity walls; the cassiterite and specularite are usually intermixed

--metaluminous to slightly peraluminous rhyolite or latite; host rhyolites may be capped with ignimbrite that is more porphyritic

-- a geochemical anomaly for Sn.

Assessment of the Silver City quadrangle found that middle Tertiary eruptive centers and intrusives have potential for tin deposits (Richter and others, 1986). Three areas (Burro Mountains, Steeple Rock area, and an area west of Lordsburg) were delineated as having potential for rhyolite-hosted tin deposits. A mineral resource assessment of the Black Range Primitive Area (Ericksen and Leland, 1984; Ericksen and others, 1970) noted that small amounts of cassiterite were recovered from veins in a 28-m.y.-old tin-bearing rhyolite (Duffield and others, 1990) of the Mogollon-Datil volcanic field along Taylor Creek. Ericksen and Leland (1984) suggest that similar deposits may exist in the Black Range Primitive Area, which is partly in Grant County.

Grades and Tonnages

The grade-and-tonnage model of rhyolite-hosted tin (Singer and Mosier, 1986) has a median tonnage of 1,000 tonnes. Ninety percent of the deposits contain 230 tonnes or greater, and 10 percent contain 4,200 tonnes or greater. The median grade of these deposits is 0.38 percent Sn. Ninety percent of these deposits contain 0.14 percent Sn or greater, and 10 percent contain 1.1 percent Sn or greater. The grade–and– tonnage model shows that the contained tin in these deposits is about two orders of magnitude less than that of the world's principal mined lode tin deposits, such as tin greisens, veins, and skarn deposits. Duffield and others (1990) note that in spite of hundreds of these deposits being identified in Mexico, the amount of tin reserves are trivial compared to world reserves.

Economic Significance

Tin is considered by the U.S. to be a strategic material; tin is part of the National Defense Stockpile. In 1993, the U.S. produced only small quantities of tin concentrates from a placer deposit in Alaska. This country has a net import reliance of 81 percent for tin, with the bulk coming from Brazil, Bolivia, China, and Indonesia. U.S. identified resources of tin are insignificant, although world resources are sufficient to sustain current production rates well into the next century (U.S. Bureau of Mines, 1994, p. 182). Rhyolite-hosted tin deposits are small, but are common in northern Mexico, and occur in the northern Franklin Mountains of Texas (Pyron, 1980; Goodell, 1976; Harbour, 1972; Richardson, 1906; and Weed, 1901). Because of the typically small tonnage of this deposit type, undiscovered rhyolite-hosted tin deposits in the study area would probably be small, low grade, and of questionable economic value.

GOLD PLACERS

Characteristics

Gold placers develop when weathering of gold-bearing source rocks results in natural preconcentration of gold on or near a bedrock surface by gravity, solifluction, or other process. Gravity and stream action may further concentrate gold into paystreaks in alluvium, on a riffled bedrock surface, or on impervious layers within the alluvium. Finally, the deposits must be preserved as a gold concentration. Probable source rocks of most placer gold include gold-bearing quartz veins, felsic intrusions, base metal sulfide deposits, older placers, and other gold-bearing deposits (McLeod, 1984). Geologic indicators of placer deposits include the presence of known or unknown hard-rock gold deposits, an ancient or modern drainage system to concentrate gold particles, concentrations of black sand in stream beds, and cobble-sized clasts of massive hematite.

Gold placers have been an important source of gold for New Mexico, with the first known production occurring in 1828 (McLemore, 1994). Mining districts, such as Elizabeth-Baldy, Old Placers, New Placers, and Orogrande (all outside of the study area), have produced gold from drainages below vein and skarn deposits (North and McLemore, 1986; and Johnson, 1972). Several areas within the Mimbres Resource Area have produced minor amounts of gold from placer operations (Wilson, 1937; Johnson, 1972; Richter and others, 1986; and Hammarstrom and others, 1988). McLemore (1994) shows 7 gold placer mining districts in the study area.

In the Silver City quadrangle, Richter and others (1986) found that a restricted part of the Gila and San Francisco River drainages has potential for gold placers. Small deposits undoubtedly occur elsewhere in the study area near where lode gold deposits are located. The Lower Cretaceous Glance Conglomerate in Gold Hill district is a known source of fossil placer gold. In the Douglas quadrangle, Hammarstrom and others (1987) outline tracts of basal Precambrian clastic sedimentary units including the Bolsa and Bliss Formations that were favorable for the occurrence of fossil gold placers. Areas favorable for the occurrence of modern gold placers were delineated in Pleistocene gravels in pediments rimming the Little Hatchet Mountains where known placer deposits occur. The high cost of dry placer mining has discouraged development of known placers and exploration in this semi-arid part of New Mexico. Some types of deposits may contain gold of such a fine grain size that it floats off on the surface tension of the water; ordinary placer-mining techniques may not recover the gold economically.

Grades and Tonnages

The grade-and-tonnage model for gold placers (Orris and Bliss, 1986) has a median tonnage of 1.1 million tonnes. Ninety percent of the deposits are 22,000 tonnes or greater, and 10 percent are 50 million tonnes or greater. The median gold grade is 0.2 g/t with 90 percent of the deposits having a grade of 0.084 g/t or greater and 10 percent have a grade of 0.48 g/t or greater. Ten percent of these deposits have silver grades of 0.036 g/t or greater. The deposit model, however, may not reflect the true grade and tonnage of desert placer deposits, such as those that are found in the study area; information on desert gold placers was not used in compiling the deposit model.

Economic Significance

Numerous small gold placer mines are active in the U.S., mostly in Alaska and the western states (U.S. Bureau of Mines, 1994, p. 72). McLeod (1984) estimates that gold placers account for $^1/_3$-$^1/_4$ of total past gold production worldwide. In New Mexico, however, the economic potential of placer deposits is limited because most of the economic placers in the state have been identified and worked by a myriad of prospectors. Most streams draining mining areas in New Mexico contain traces of gold attractive to the recreational panner; however, the lack of water in much of the study area, and the high cost of dry placer mining, has discouraged development of known placers and exploration. New technology minimizing the need for water may stimulate activity. Small deposits undoubtedly occur elsewhere in the study area near where lode gold deposits occur, and the persistent gold panner will be able to produce minor amounts of gold.

According to Lasky (1936), a map of the placer ground in the Silver City area would be a map of the drainage area of the pre-volcanic rocks because, in these areas, even the smallest arroyos and intermittent channels have yielded gold. The most productive placer grounds are north of San Jose Mountain and just east of the town of Central in Grant County, where gold has been derived from veins. Lasky (1936) states that experienced gold panners found that the gold content of the sands increased steeply wherever an arroyo crossed a vein, then abruptly declined. Gold dust with an average fineness of 0.705 (fineness of pure gold is 1) is the most common product of the placers; however, nuggets the size of a small lima bean have been won.

OOLITIC IRONSTONE

Characteristics

Oolitic ironstone deposits were modeled by Maynard and Van Houten (1991). Deposits of this type form when iron silicate- and iron oxide-mineral-rich beds with distinctive

oolitic texture are deposited in shallow-shelf to intertidal clastic-dominated environments. In older deposits, hematite and chamosite are the chief ore minerals; in younger deposits goethite and berthierine are ore minerals. Siderite is a common replacement mineral, pyrite may be found locally as a replacement mineral, and magnetite is found occasionally. Deposits form tabular bodies 2-5 m thick and 2-10 km wide. Major deposits occur in undeformed and gently folded strata.

Oolitic ironstone deposits typically develop on a shallow shelf closed to transition from nonmarine to marine environments. A standard vertical sedimentary sequence is black shale at the base, overlain by gray shale and siltstone, sandstone with graded bedding and hummocky cross-stratification suggesting a marine shelf reworked by waves, and sandstone or oolitic ironstone with bipolar cross-stratification suggesting intertidal deposition (Maynard and Van Houten, 1991). Three-quarters of these deposits are found at the top of this sedimentary cycle. The deposits may be geophysically marked by positive gravity anomalies. Magnetite-bearing deposits may be distinguished by magnetic highs. Hematite and glauconite in the heavy mineral fraction of stream-sediment samples may be indicative of this type of deposit.

In the Silver City quadrangle, Richter and others (1986) delineate two favorable areas based solely on the distribution of Bliss Sandstone—one in the Fleming-Chloride Flat area and the other northwest of the Pinos Altos district. Identified resources in these deposits were estimated to be millions of tonnes Fe; undiscovered resources were estimated at hundreds of millions of tonnes Fe.

Grades and Tonnages

The grade-and-tonnage model for oolitic ironstone deposits (Orris, 1991) has a median tonnage of these deposits is about 60 million tonnes. Ninety percent of the deposits are 40 million tonnes or greater and 10 percent of the deposits were 890 million tonnes or greater. The median iron grade is 41 percent iron. Ninety percent of the deposits were 30 percent Fe or greater and 10 percent of the deposits were 50 percent Fe or greater. Fifty percent of the deposits had 8.6 percent silica or greater and (or) 0.26 percent P_2O_5 or greater. Ten percent had 20 percent silica or greater and (or) 1 percent P_2O_5 or greater.

Economic Significance

In 1993, the U.S. had a net import reliance of 12 percent for iron ore. Imports came from Canada, Brazil, and Venezuela. U.S. resources are estimated to be about 110 billion tonnes of ore, mainly in low-grade taconite ore from the Lake Superior district that requires beneficiation and agglomeration to be used commercially. Oolitic ironstone deposits are large

deposits that are rich in iron. This type of deposit was an important source of iron from 1850 to 1945, but its importance has declined owing to competition from Precambrian banded-iron deposits. Kelley (1949) discussed the potential for mining some of the oolitic ironstone beds in Bliss Sandstone in southern New Mexico as a source of iron ore.

MARINE EVAPORITE GYPSUM

Characteristics

In the descriptive mineral deposit model, Raup (1991) notes that marine evaporite gypsum deposits form on the continental margin where marine basins have a periodic inflow of sea water, which is the major source of the calcium sulfate that forms gypsum. Basins subside at a moderate rate during deposition of evaporites, permitting occasional influx of seawater to maintain water levels despite evaporation. Marine evaporite gypsum deposits are frequently of large aerial extent, covering many square kilometers, but the size of the marginal basins in which they form may be highly variable. Thicknesses of the deposits range from 10 m to 50 m.

Many gypsum deposits form from hydration of anhydrite. The completeness of the alteration process may greatly affect the purity and usefulness of a deposit. Groundwater dissolution can modify or destroy a deposit. Some important criteria for locating marine evaporite gypsum deposits are:

-- depositional basin near a continental margin
-- thickness of minable bedded gypsum deposit ranges from 10 to 50 m
-- high response on neutron log because of large amount of water of crystallization
-- basin edge sediments are of higher than normal salinity.

For a marine evaporite gypsum deposit to be of commercial interest, the gypsum must be sufficiently pure that a minimum of physical beneficiation is needed for the intended product. Transportation is also a major cost, so the deposit must be easily accessible and proximal to a population center or transportation facility. Weber and Kottlowski (1959) identified areas in the Organ, San Andres, northern Franklin, and Big Hatchet Mountains where gypsum deposits occur.

Grades and Tonnages

The grade-and-tonnage model of marine evaporite gypsum deposits (Orris, 1992) has a median tonnage of 280 million tonnes. Ninety percent contain 14 million tonnes or greater, and 10 percent contain 5,600 million tonnes or greater. The median grade is 90.7 percent gypsum. Ninety percent of the deposits contain 81.7 percent gypsum or greater, and 10

percent contain 99.8 percent gypsum or greater.

Economic Significance

The U.S. has a net import reliance of 29 percent for gypsum. Major imports of gypsum are from Canada, Mexico, and Spain. Domestic sources are adequate, but unevenly distributed (U.S. Bureau of Mines, 1994, p. 77). The median tonnage of marine evaporite gypsum deposits is about 20 times that of lacustrine gypsum deposits, and the marine deposits are somewhat higher grade.

LACUSTRINE GYPSUM

Characteristics

Deposits of this type form from chemical precipitation in saline water in nonmarine inland lakes of Jurassic, Cretaceous(?), and Cenozoic age (Weber and Kottlowski, 1959). The conditions required for the deposits to form are a hot dry climate with a high evaporation rate that exceeds precipitation and inflow of surface water, a continued resupply of water containing dissolved salts, and, in order to form thick deposits, a gradual subsidence of the area to allow accumulation of evaporite minerals and associated sediments (Papke, 1987). Faulting associated with regional tectonic extension, such as the Basin-and-Range may create closed basins (lakes) in which great thicknesses of fluviatile clastic sediments and volcanic material are deposited. Commonly, lacustrine gypsum deposits are interbedded with red beds, volcanic tuffs, and nonmarine limestone; gypsum may be laminated and form thick beds. Some important criteria for locating lacustrine gypsum deposits are:

-- lacustrine sediments
-- redbed clastic sedimentary rocks
-- closed intermontane basins.

Grades and Tonnages

A preliminary grade-and-tonnage model for lacustrine gypsum deposits (Orris, 1992) has a median size of about 14 million tonnes. Ninety percent of the deposits are 780,000 tonnes or greater, and 10 percent of the deposits are 247 million tonnes or greater. The median grade for lacustrine gypsum deposits is 85 percent gypsum. Ninety percent of the deposits have a grade of 74 percent gypsum or greater, and 10 percent have a grade of 96 percent gypsum or greater. Lacustrine gypsum deposits have a median tonnage about 5 percent that of marine deposits, and the grade is somewhat lower.

Economic Significance

The U.S. has a net import reliance for gypsum, which is imported mainly from Canada, Mexico and Spain. Domestic sources are adequate but unevenly distributed (U.S.

Bureau of Mines, 1994, p. 77). Transportation costs are an important consideration in the market for gypsum. As the population of southern New Mexico continues to grow, local sources of clean, white gypsum near population centers will be sought.

SEDIMENT-HOSTED COPPER

Characteristics

Sediment-hosted copper deposits are stratabound concentrations of copper-sulfide minerals or native copper in sedimentary rocks (Cox, 1986f). These deposits are commonly associated with continental redbed sequences, but they are localized in reduced green, gray, or white beds within the sequence, or within laminated carbon-rich shales that overlie the redbeds (Ludington and others, 1992). Both the boundaries between oxidized and reduced sedimentary strata and the permeability of the individual beds may act as ore controls. Ore minerals are typically chalcocite, bornite, and other sulfur- and iron-poor copper sulfides.

Ludington and others (1992) list six factors that must occur in order for sediment-hosted copper deposits to form:

-- there must be a source of copper, such as copper-rich basement or sedimentary rock

-- a brine must be present to dissolve copper as a stable copper chloride complex; the brine may come from evaporites

-- there must be an oxidizing environment, such as ferric iron in redbeds or in subaerial basalt, to maintain stability of the copper chloride complex

-- permeable beds must be available through which the copper-rich brine may move to a site of deposition

-- a source of energy is necessary to cause fluids to flow; this may be from basin compaction, heat from burial, or intrusion of a diapir

-- a reductant, such as fossil plant remains (e.g., wood, algal mat), petroleum or natural gas in paleoaquifers, or early diagenetic pyrite (Kirkham, 1984), is required to cause deposition of native copper and, where the ore mineral is chalcocite, a source of sulfur is necessary.

Conditions that may be suggestive of the presence of sediment-hosted copper deposits are low latitude, arid-continental and shallow-marine sedimentary sequences and extensive redbeds or other oxidized aquifers containing green or gray shale, siltstone, and sandstone.

In the Silver City quadrangle, Richter and others (1986) noted that the Permian Abo Formation, exposed locally, has no reported indication of mineralization, but it is a favorable host for sediment-hosted copper deposits elsewhere in New Mexico.

Grades and Tonnages

The grade-and-tonnage model (Mosier and others, 1986) shows the median tonnage of sediment-hosted copper deposits to be 22,000,000 tonnes; the median grade is 2.1 percent copper. Ninety percent of the deposits contained 1,500,000 tonnes or greater, and 10 percent contained 330 million tonnes or greater. Ninety percent of the deposits had a grade of 1.0 percent Cu or greater, and 10 percent had a grade of 4.5 percent copper or greater. The grade–and-tonnage model contains data for 2 sediment-hosted copper deposits (Nacimiento and Pintada-Stauber) in New Mexico; thus, the model is considered suitable for estimates of undiscovered mineral resources in the study area.

Economic Significance

There are large sediment-hosted copper deposits in the U.S. and worldwide. Worldwide, 15-20 percent of copper production and reserves are in deposits of this type, primarily from a few large deposits in Zambia and Zaire copper belts. Sediment-hosted copper deposits have had substantial past production in New Mexico.

CONCLUSIONS

Mineral deposit types that are known to occur, or that may occur, in the Mimbres Resource Area are quite diverse. They range from porphyry deposits that may contain hundreds of millions of tonnes of ore that may be mined by open pit methods and heap leaching, to rhyolite-hosted tin deposits that may contain tens or hundreds of tonnes of ore in very thin veins that could be mined at a very small scale or not mined at all. These diverse deposits have formed from igneous activity far beneath the Earth's crust (e.g., porphyry molybdenum deposits), or from processes that occurred on the surface (e.g., gold placer deposits). Some deposits form in stockworks where large areas are fractured and mineralized with disseminated sulfide minerals, while others may have formed as low temperature replacements through preferential dissolution of carbonate rocks. Some deposits, like porphyry deposits, may be the economic backbone of the region and regularly produce copper and other metals used in industry. Other deposits, like tungsten skarn deposits or epithermal manganese veins, are typically mined sporadically, supplying their strategic commodities only when prices for the commodity are high.

TOPOGRAPHIC, GRAVITY AND AEROMAGNETIC MAPS OF THE MIMBRES RESOURCE AREA

by

Gerda A. Abrams and Douglas P. Klein

INTRODUCTION

Topographic, gravity and aeromagnetic maps were used together with geologic, geochemical and aerial gamma-ray data (U, Th, and K) and seismic refraction profiles in evaluating the mineral potential of the Mimbres Resource Area. The maps presented here are a color-contour map (**figure 3-1**), a complete Bouguer gravity anomaly map with gravity station locations (**figure 3-2**), and a reduced-to-the-pole aeromagnetic anomaly map (**figure 3-3**).

The study area contains Precambrian basement rocks, Paleozoic and Mesozoic sedimentary rocks, intrusive and extrusive rocks, calderas, faults, and mineral districts (**figure 1-4, figure 1-5, and figure 1-6**). Because ore deposits are frequently associated with caldera-related rocks and ring faults, it is important to recognize these volcanic and intrusive features using geophysical techniques which penetrate into the subsurface.

DESCRIPTION OF MAPS

Topographic Map

Figure 3-1 shows digital color-shaded topography of the Mimbres Resource Area created from the 3-second GEO tape series (Elassal and Caruso, 1983). The map was created using program GDCLRX (Robert Simpson, U.S. Geological Survey, unpub. Code). Each color indicates an elevation range (meters) above sea-level as shown on the bar scale. Elevations range from a minimum of 1,050 m at the Gila River as it crosses the western border of the area, to a maximum of 3,100 m at McKnight Peak in the Black Range.

Topographic expression of the Basin-and-Range and Rio Grande Rift is manifest as a series of mountains and intervening valleys. For instance, the San Andres and the Franklin Mountains near the eastern boundary of the study area have bordering deep basins to the east (Tularosa Basin) and west (Jornada and Mesilla Basins). Animas Range, in the southwest part of the area, is bordered by basins to the east (Playas Valley) and west (Animas Valley).

Drainages within the Mogollon Plateau typically follow zones of geologic weakness. Although numerous calderas are present in the Mogollon Plateau area and the areas of the Peloncillo and Animas Mountains, none have obvious expression on the topographic map.

Bouguer Gravity Anomaly Map

Gravity data for this study consist of about 1,000 gravity stations (Charles E. Heywood, WRD, Albuquerque, N. Mex., written commun., 1995) and about 6,000 stations from the gravity data base of the Defense Mapping Agency. Complete Bouguer gravity anomaly values were calculated using the program BOUGUER (Godson and Plouff, 1988). A 2.67 g/cm^3 reduction density was employed, which approximates the average density of the Earth's crust. Observed gravity values were adjusted to conform to the International Standardization Net of 1971 (International Association of Geodesy, 1974). Theoretical gravity values were calculated using the 1967 Geodetic Reference System (International Association of Geodesy and Geophysics, 1971). Cordell and others (1982) give a complete description of the gravity-reduction equations and approximations used. Gravity effects of terrain were corrected using the method of Plouff (1977) to a radius of 166.7 km from each gravity station. Terrain corrections are the most likely source of error in the data-reduction process due to the coarseness of the terrain grid. Terrain corrections may account for errors of as much as 20 percent (Simpson and Jachens, 1989; R.W. Saltus, USGS, spoken commun., 1993), which translates to 6 mGal maximum possible error at the highest elevations.

Data were projected using a Lambert conformal conic projection, then gridded using a minimum curvature algorithm (Briggs, 1974; Webring, 1981) at a 0.5–km grid interval. The grid interval has an effect on the nature of the resulting map; a small grid spacing can accommodate smaller details, while larger grid spacings properly represent only the larger features (Nettleton, 1962).

The complete Bouguer gravity anomaly map (**figure 3-2**) shows variations in the gravitational field owing to horizontal variations in the density of surface and subsurface rocks. Red colors indicate areas of high gravity values (mass excess with respect to the reduction density) and may correspond to uplifts, horst blocks, and dense mafic rock masses; purple and blue colors indicate areas of low gravity values (mass deficit with respect to the reduction density) and may correspond to sediment-filled grabens, tuff-filled calderas, and felsic intrusions and batholiths. Bouguer values range from a low of -229 mGals in the center of the Mogollon Plateau to a high of -112 mGals overlying Bishop Cap. In the Basin-and-Range area, anomalies are mostly elongate in a northerly direction; gravity highs and parallel lows are caused by density contrasts between bedrock horsts and low density basin fill.

Aeromagnetic Anomaly Map

The aeromagnetic map (**figure 3-3**) is based on gridded data extracted for the study area from a regional compilation covering the State of New Mexico (Cordell, 1983). The aeromagnetic map is shown in color-contour, with red colors showing areas of relatively high

magnetic field strength, and purple and blue colors showing areas of relatively low magnetic field strength. The map was constructed using data from eight aeromagnetic surveys (**figure 3-3**; **table 3-1**), each flown at different specifications using both fixed-wing aircraft and helicopter. Surveys were joined and smoothed at the boundaries to assist in interpretation of the map. According to Cordell (1983), "Each survey was digitized, gridded, level-shifted where necessary, and converted to a uniform DGRF (Definitive Geomagnetic Reference Field) or related residual." In spite of the smoothing, discontinuities occur at the boundaries between surveys and appear as linear features.

Aeromagnetic anomalies express variations in the strength of the Earth's total (scalar) magnetic field and are caused by contrasts in rock magnetization. Magnetization of a rock is the vector sum of its induced and remanent magnetization components. Both result from small fractions of magnetic minerals, mostly magnetite, in the rocks. Induced magnetization is proportional to magnetic susceptibility, whereas remanent magnetization is dependent on the geologic history of the rock.

Because of the inclined polarization of the Earth's inducing field at the latitude of New Mexico, positive magnetic anomalies are shifted to the south of their source, with a smaller amplitude anomaly of negative sign occurring on the north side of the source. However, these shifts have been removed through a mathematical transformation called reduction-to-the-pole (**figure 3-3**), so the magnetic data appears as if measured at the north magnetic pole (where the Earth's magnetic field is vertical) (Hildenbrand, 1983). Red colors show areas of relatively high magnetic field strength.

Surface rocks in the Mimbres Resource Area include effectively non-magnetic Tertiary and Quaternary sedimentary rocks, ash-flow tuffs with dominant remanent magnetization that can be either normal or reversed, and high-susceptibility intrusive igneous rocks. Highest magnetic intensities are located over topographic highs where normally polarized volcanic rocks were closest to the magnetometer elevation. In contrast, the most extreme magnetic lows are associated with certain reversely polarized rocks. Hydrothermally altered rocks show little to no magnetization and are, therefore, also associated with magnetic lows. Igneous and metamorphic rocks have significan magnetite and produce large magnetic anomalies. Sedimentary rocks are effectively non-magnetic. Thus, the sedimentary cover does not hinder detection of buried intrusive igneous rocks and structural trends within the buried crystalline basement rocks, except by placing the magnetic sources at greater distance from the sensor.

RELATIONS OF GRAVITY AND MAGNETIC ANOMALIES TO GEOLOGY AND MINING DISTRICTS

Gravity and aeromagnetic data contain information that can help identify geologic

environments that might be associated with mineral deposits. Selected geophysical anomalies in **figure 3-2** and **figure 3-3** are discussed in relation to major geologic structures and lithologies. Anomalies in the vicinity of mineral districts are considered in the sections on mineral deposits for each county (see McLemore and Sutphin, and McLemore and others, this volume). Anomalies are numbered and given a letter symbol G (gravity) and M (magnetic).

Mogollon Plateau is characterized by a broad long-wavelength gravity low; a steep gradient on the west side of the Mogollon Mountains indicates a range-front fault and a contrast between the Mangas Trench and the mountains. The Mangas Trench has steep range–front faults on either side. Farther east, the regional gravity low corresponds to the central part of the Datil-Mogollon volcanic field. The gravity suggests low density volcanic rocks (2-3 km thick; Rhodes, 1970), as does Jaksha's (1982) interpretation of a seismic line crossing the Datil-Mogollon volcanic field. In contrast, other investigators have inferred the presence of a batholith at shallow depth comparable to the one underlying the San Juan volcanic field (Plouff and Pakiser, 1972; Schneider and Keller, 1994).

The Piños Altos Range lies partly within the Twin Sisters caldera (**figure 1-6**), which is overlain by both a gravity low (G3) indicating low density volcanic rocks and a -900 nT magnetic low (3M), which possibly indicates reversely magnetized rocks. South of the caldera are two 350-400 nT magnetic highs (M3a, M3b) that lie on the edges of known porphyries. Magnetite skarn at three of the four known major porphyry copper deposits in the Mimbres Resource Area (Chino, Santa Rita, and Hanover-Ferro) are associated with magnetic highs (Jones and others, 1964, 1967). The Tyrone porphyry copper deposit coincides with a magnetic low (M3c), possibly due either to hydrothermal alteration that destroyed the magnetite or to a non-magnetic silicic intrusion into more magnetic country rock.

Emory mining district lies within Emory caldera (**figure 1-6**) and east of the porphyry districts mentioned above. The caldera lies in a large gravity low (G4); the southern part of the caldera is clearly defined by a gravity gradient. East of the Emory caldera and about one mi northeast of Hillsboro, a circular magnetic high anomaly (M5) marks the Copper Flat quartz monzonite porphyry stock.

In the southern and eastern parts of the study area, steep gravity gradients located between the valleys and ranges indicate range-front faults. For example, gradients flanking the San Andres Mountains mark the edges of the Jornada del Muerto basin on the west and the Tularosa basin on the east. The gravity gradient coinciding with the edge of the Tularosa Basin extends south along the Franklin Mountains. Other steep gravity gradients lie between the Peloncillo Mountains and the Animas Valley, between the Animas Valley and the Animas Mountains, and between the Animas Mountains and Playas Valley.

The linear gravity high overlying the San Andres (G6a) and Franklin Mountains (G6b) is interrupted by a gravity low in the Organ Mountains area (G6c) caused by intrusion of the Organ Mountains quartz monzonite batholith. The gravity high overlying the Franklin Mountains continues to the north and west over Bishop Cap and the Rio Grande Rift. Decker and others (1975) suggest that the positive gravity anomaly over the Rio Grande Rift requires that dense mafic rock or a tabular high-density intrusive is present in the Rift. The southern half of the Organ Mountains, Franklin Mountains, and an area near the Rio Grande are covered by a magnetic high (6M) that may be caused by basaltic andesite flows (Chapin and others, 1975).

Doña Ana caldera (**figure 1-6**) is characterized by a gravity high and a magnetic anomaly high (G7, M7) that may be caused by intrusions. The gravity high wraps around the northwest side of the caldera. Tortugas district (G8, M8) lies on a gravity gradient that joins the Doña Ana caldera and the Franklin Mountains. The magnetic low overlying the district may be due to hydrothermal alteration.

Gravity lows (G9) over the Rio Grande Rift west and east of the San Andres and Franklin Mountains are caused by valley fill. Analyses of gravity data by Ramberg and others (1978) result in estimates of 2-3 km of sedimentary deposits within the Tularosa, Mesilla, and Mimbres basins (major basins within the Rio Grande Rift). The Lordsburg mining district (G10, M 10) in the Animas Mountains is overlain by coincident gravity and magnetic anomaly highs, indicating intrusions at depth (Elston, 1984). Calderas in the southwest corner of the study area have various geophysical signatures.

The highest amplitude magnetic anomaly in the study area (M11, greater than 1,000 nanoTeslas) coincides with the Muir caldera (**figure 1-6**) south of Lordsburg. Two small gravity highs are located over the rim of the caldera (G11a, G11b) and outside the southwest rim of the caldera (G11b). Each anomaly may be caused by distinct intrusions (Elston and others, 1983). Overlying the Rodeo caldera (**figure 1-6**) is a circular gravity low (G12) and several magnetic highs (M12) along the edge of the gravity low. These may indicate buried intrusions within the rim and beneath the caldera. Geronimo Trail caldera (**figure 1-6**) lies south of the Rodeo caldera on a gravity gradient (G13). A magnetic high (M13) over the caldera wall suggests an underlying intrusion. Silvertip district lies within the Geronimo Trail caldera in a magnetic low that was probably caused by hydrothermal alteration. Juniper caldera (**figure 1-6**) in the southern Animas Mountains, separates two gravity highs (G14a, G14b) and contains two small magnetic highs (M14a, M14b). Cowboy Rim caldera (**figure 1-6**) is expressed by a gravity high (G15) and an indistinct magnetic anomaly. A gravity and magnetic high (G14b, M15) lies between Cowboy Rim caldera and Juniper caldera to the north. Apache Hills caldera (**figure 1-6**) has both magnetic and gravity highs (M16, G16) associated with it. The area is intruded by Tertiary and Laramide

plutons and is covered by volcanic rocks.

The Little Hatchet Mountains, consisting of Cretaceous and Tertiary sedimentary and volcanic rocks, are overlain by a gravity high (G17) with local magnetic highs (M17) associated with local Tertiary intrusions. A gravity high (G18) over the Big Hatchet Mountains is probably caused by a thick section of dense carbonate rocks (Drewes, 1991).

Animas Mountains are overlain by high gravity anomalies (G14a, G14b, G15) and mostly undiagnostic magnetic anomalies, with the exception of magnetic highs M14a, M14b, and M15 that are associated with the Juniper and Cowboy Rim calderas. The central Peloncillo Mountains are overlain by a gravity high (G20). In the Peloncillo Mountains, Granite Gap mining district (M20a) and Kimball mining district (M20b) coincide with magnetic highs, whereas McGhee Peak mining district lies within a magnetic low (M20c).

Between the Big Burro and the Tres Hermanas Mountains, several gravity (G21) and magnetic highs (M21) are present, some of which lack outcrop expression. Anomalie northwest and east of Victorio Mountains are covered with Quaternary sediments. In this area, gravity highs may be caused by uplifted rocks, and magnetic highs may define possible covered intrusives within carbonate rocks.

Tres Hermanas Mountains, overlain by a gravity high (G22), are comprised of a series of Tertiary volcanic sediments and intrusions that overlie or intrude Paleozoic carbonate rocks. Magnetic data are not available for the Tres Hermanas Mountains area.

Northeast of the Tres Hermanas Mountains, carbonate and intrusive outcrops in the Florida Mountains are expressed as gravity and magnetic highs (G23, M23). These anomalies may suggest the presence of intrusions within carbonate rocks in the mountains and adjacent Mimbres Basin.

A gravity high (G24) coincides with the basalt-covered Potrillo Mountains, where carbonate and intrusive rocks are exposed. The magnetic high (M25) in the northern Potrillo Mountains may be caused by an intrusion within the carbonate rocks or by a basaltic vent.

SUMMARY

Gravity lows are associated with thick sequences of volcanic rocks in the Mogollon Plateau and elsewhere, and with sedimentary rocks and valley fill in the Basin-and-Range province. Gravity highs indicate uplifted basement and carbonate rocks in the north-south-trending mountain ranges. Steep gravity gradients locate mapped and inferred range-front faults and the contrast in density between the valley fill and uplifted bedrock.

Magnetic data show magnetic contrasts owing to structure and lithology in rocks lying beneath alluvium and volcanic and sedimentary rocks. Magnetic data may locate buried intrusions with associated mineralization. However, because of alteration and the magnetic character of the

host rock, correlations between magnetic anomaly highs and intrusions are not always consistent.

SUMMARY OF RESULTS FROM SEISMIC REFRACTION STUDY

by

Douglas P. Klein, G.A. Abrams, and P.L. Hill

INTRODUCTION

This report summarizes a geologic interpretation of seismic velocity sections that profile a total of 790 km in southwest New Mexico to assist in outlining areas favorable for mineral resource occurrences (Klein, 1995). Seismic refraction surveys are carried out to estimate the subsurface distribution of acoustic compressional velocity (Vp) and to interpret this velocity information in terms of lithology, geologic structure, and the occurrence of natural resources. Seismic sections presented here show velocity structure to a depth of 2-3 km.

Seismic refraction lines interpreted for the Mimbres study are designated 1, 2, 3, 4, 5, and 7 (no line 6) and cover a swath of the southwest Basin and Range Province, extending from the Arizona border eastward to the Rio Grande River and from the Mexican border to about latitude 32° 30' N. Lines 1, 3, and 7 traverse the axis of basins in roughly north-south directions; the remaining lines 2, 4, and 5 trend east-west and cross various ranges and basins.

Seismic data that have been collected in this region include deep-crustal refraction traverses for university research programs (**figure 3-4a**) and commercial seismic reflection profiles acquired for petroleum exploration. Results of deep-crustal refraction studies are reviewed to provide a regional setting for the higher resolution refraction data; results from seismic reflection will not be discussed.

Until 1978 there were about 36 deep borings in the region of southwest New Mexico (Thompson and others, 1978). This drilling was done mainly to evaluate petroleum potential of the Pedregosa Basin that, in Paleozoic time, accumulated about 3 km of Paleozoic sedimentary rock (Zeller, 1965; Thompson and others, 1978). Many drill holes in the basin are sufficiently near the available seismic sections to provide correlations of velocity to lithology and to estimate errors associated with the depth interpretations to various lithologic units.

REGIONAL CRUSTAL SETTING

Regional seismic data penetrate through the Earth's crust and into the uppermost mantle that, in southwest New Mexico, begins at a depth of about 30 km. Traverses intended for deep-crustal studies do not resolve upper crustal features as well as data in this reeport; however, regional data provide a broad perspective of the crust that can be useful in understanding many of the shallow crustal features. Seismic refraction data acquired for studying large features deep in the Earth's crust are reviewed by Braile and others (1989).

Sinno and others (1986) present three profiles that are within the study area (**figure 3-4**).

They show a composite interpretation of crustal velocity for a profiles within an area bounded by lat. 32˚ N. to lat. 33˚ N. and long. 109˚ 00'W. to long. 104 ˚ 30'W. Deep crustal traverse A-A', from Deming to the Franklin Mountains (Sinno and others, 1986) is within the area of higher-resolution data of this report. This line shows the crystalline crust having a velocity (Vp) ranging from 5.9 km/sec at 1-2 km depth to 6.7 km/sec depth at the base of the crust. Mantle velocity is interpreted as 7.7 km/sec beneath the Rio Grande area, and increases both eastward and westward. Westward, mantle velocity is about 8.0 km/sec near lat 109ºW. (**figure 3-4b**). Crustal thickness is interpreted to vary from 27 km in the Rio Grande river area to 30 km in the Basin and Range Province to the west. To the east, the crust thickens to nearly 50 km.

Southwestern New Mexico is underlain by a thinner crust than the continental interior east of the Rio Grande (Sinno and others, 1986) (**figure 3-4b**). Rio Grande Valley is anomalous because it has lower-velocity upper mantle and a thinner, higher-velocity crust compared to bordering areas. Beneath Rio Grande Valley, low-velocity mantle may imply an underlying thermal anomaly with melting just below the crust; higher-velocity crust indicates the presence of mafic intrusions (Sinno and others, 1986). This result and the results of other workers indicate that the Rio Grande area is characterized by concentrated crustal faulting and magmatism associated with low electrical resistivity and high heat flow (Seager and Morgan, 1979), along with the seismic features just mentioned. Magmatism and faults in the Rio Grande area allow geothermal circulation, resulting in the potential for geothermal resources (Swanberg, 1979).

The thin crust of southwestern New Mexico is characteristic of the Basin-and-Range Province as a whole (Eaton, 1982). Crustal characteristics of the Basin-and-Range province are probably the result of widespread felsic magmatism during Mesozoic/mid-Tertiary time (Eaton, 1979, 1982). A consequence of this magmatism is development of a rich base- and precious-metal province.

Although deep-sensing refraction data provides a regional perspective for the tectonic activity involved in creation of geothermal and mineral resources of the area, it is imprecise for locating features associated with mineral deposits. For example, Emory Caldera, which is located about 50 km north of Deming (**figure 1-6**) within the Mogollon volcanic field (Ericksen and others, 1970; Elston, 1984; McIntosh and others, 1992), does not produce a recognizable signature in a regional refraction model of line C-C' (**figure 3-4a**) (Sinno and others, 1986). Also, neither the Bursum caldera nor the Mogollon volcanic field itself are apparent in regional refraction velocity results for line E'-E' (**figure 3-4a**); Jaksha, 1982). However, a correlation of greater seismic refraction delay times with a gravity low over the volcanic field has been shown (Jaksha,1982); greater delay times and low gravity data together are consistent with a depression of subvolcanic crystalline basement beneath a thick volcanic section. Seismic reflections near 21 km depth beneath

the western part of the volcanic field may represent melting in the middle crust (Jaksha, 1982). An alternative hypothesis implicit from considerations of crustal magma intrusion and differentiation (Johnson, 1991), is that these reflections are from residual mafic sills related to earlier melting beneath the Mogollon volcanic field. Deep seismic data in southwest New Mexico have not provided clear evidence of an upper crustal silicic batholith (top at 3 to 10 km) beneath this volcanic field or its calderas, although combined gravity and seismic data are consistent with such a batholith (Coney, 1976; Jaksha, 1982; Schneider and Keller, 1994).

SEISMIC REFRACTION DATA

Data were aquired using shotpoint intervals of 3.2 km with two shots at each shotpoint for backward and forward recording; receivers were spaced at intervals of 201 m. Data processing was based on reversed travel-time curves, and depth-velocity sections were derived using interactive computer programs, where velocity is assumed to be isotropic and to increase vertically downward. A surface layer of variable thickness (seldom more than 150 m) and constant velocity of 0.85 km/sec was incorporated into all velocity sections to account for dry, porous, and unconsolidated rock or soil. Details of data acquisition and processing are described by Ackermann and others (1982, 1986, 1994).

Variations in velocity were interpreted in blocks 4 km -10 km long. Boundaries of the blocks are indicated by near-horizontal lines that define the refracting horizons, and near-vertical lines between blocks of differing velocity. Velocity within a block is representative of the average velocity of the block. Where velocity changes are poorly resolved, dashed boundary lines were drawn. More generally, uncertainties may arise elsewhere as well (where not dashed), because a unique solution is not inherent in seismic-refraction data interpretation.

RELIABILITY OF VELOCITY STRUCTURE

Reliability of the modeled velocity structure was examined by considering consistency of models at line intersections and by correlation between seismic velocity units and drill hole lithologic logs. Five intersections provided useful comparative data (intersections of lines 1 and 4, lines 1 and 5, lines 2 and 3, lines 3 and 4, lines 4 and 7, and lines 5 and 7). On the average, layer depths are consistent within about 50 m, and velocity values correspond to within about 0.2 km/sec.

Twenty–seven deep drill holes in southwest New Mexico are along the traverses of the present data (**table 3-2**). Lithologic logs for 14 drill holes (Thompson and Bieberman, 1975; Foster, 1978; Thompson and others, 1978; Thompson, 1981) were used to estimate errors in depths interpreted from velocity sections. About 65 percent of the refraction depth determinations fall within 20-percent error lines; about 90 percent of the points fall within 25-percent error (**figure 3-5**). Geologic units encountered in drill holes are shown in **table 3-3**.

Published lithologic logs (**table 3-2**) have been compared to the seismic velocity sections to gain insight into the velocity-lithology relationships and to investigate the accuracy of the present sections. **Figure 3-6** shows velocity ranges encountered in the present data for correlative geologic units. Velocity-lithology correlations show a wide overlapping range, indicating that lithologies need to be interpreted carefully.

SEISMIC VELOCITY LAYERS

Seismic sections show a range in velocity of 2-6 km/sec. Various blocks resulting from the seismic interpretation seem to group into 3-5 "layers." A "layer" may have lateral variation among the blocks, but is used here in the sense that the lateral changes in velocity within a layer are typically less than vertical changes in velocity across layers. For the present description the dry, loose, weathered, near–surface materials (the layer with assigned velocity of 0.85 km/sec) is assigned to layer 1, and the next two or three mid-level layers are considered together. This results in three significant layers numbered downward. Lithologic inferences for the layers are based on published rock-velocity relationships (Christianson, 1989), drill-hole correlations, and surficial geology.

Layer 1 (0.85 to 3.0 km/sec)

The uppermost 50 to 150 m of Layer 1 (0.85 km/sec) represents dry, loose, surficial material. The higher velocity 1.6 to 3.0 km/sec material of layer one often disappears beneath ranges. In the basin areas, layer 1 is believed to be a porous zone of unconsolidated to poorly consolidated gravel, alluvium, sand, clay, and possibly thin layers of volcanic rock. Most of this material is probably Quaternary in age. Where velocities are about 1.8 km/sec or greater, the layer is probably water saturated (Pankratz and others, 1978). Water can probably be extracted from rocks and loose material when porosity exceeds about 20 percent. Porosity-velocity relations indicate that shallow basin aquifers may occur where velocity in layer 1 is in the range 2-3 km/sec (Zohdy and others, 1974, fig. 63, p. 83). Thickness of this layer commonly is 150-400 m in basins, but as high as 700 m in parts of Playas Valley (line 2), Hachita Valley (line 4), Animas Valley (line 5), and in Deming Basin (lines 5 and 6).

Layer 2 (2.7 to 4.5 km/sec)

Velocity sections show two or three discrete layers between layer 1 and the deepest layer detected. Intermediate layers are grouped herein as layer 2. Various zones, or sub-layers, within this layer show velocity differences of about 0.6 km/sec, which is believed significant and resolvable, but specific lithologic correlations to velocity units within this layer are equivocal (**figure 3-6**). The velocity range in this layer encompasses many rock types; velocity changes may relate to compaction of some similar rock types as well. As a generalization, layer 2 most likely consists of Tertiary and Mesozoic clastic and volcanic rock and may include some porous,

impure limestone. Where seismic velocities near 4 km/sec are encountered, the geologic units may have increased cementation and induration, denser welding, or an increased fraction of carbonate rocks, all of which increase velocity (Christianson, 1989). Units having velocities near 3 km/sec may have porosities of about 10 percent or greater (Zohdy and others, 1974, p. 83), which may be sufficient to form aquifers.

Layer 3 (seismic basement: 4.0 to 6.1 km/sec)

Layer 3 is the deepest and highest velocity refracting horizon detected, and forms the cores of mountain ranges as well as the floors of basins. Layer 3 (referred to as seismic basement) does not necessarily represent geologic basement composed of igneous and metamorphic rock. Rock with velocities in the range of 4.0 to 5.1 km/sec may represent plutonic rock, metamorphic rock, strongly welded volcanic rock, and carbonate or silica-cemented sedimentary rock (**figure 3-6**). Units with velocities exceeding 5 km/sec probably represent rocks with low fracture density and (in igneous or metamorphic rock) high mafic composition (Christenson, 1989). Where this layer is shallow below valleys, uplifts or intrusions may present barriers to ground water flow and are possible targets for mineralized rock. Where layer 3 is undetected, such as in the southern Playas and Animas Valleys, there is insufficient distance between shotpoints and detectors to penetrate unusually thick deposits of Tertiary sedimentary and volcanic rock.

SUMMARY OF BASIN DEPOSITS AND BEDROCK STRUCTURE

Figure 3-7 shows the location of shotpoints for the 6 lines discussed along with complete Bouguer gravity contours. In the following summaries of each line, locations are designated by shotpoint number, line and number and line segment. For instance, SP1-12(B) indicates line 1, shotpoint 12 (SP12), segment B. Segments and shotpoints of each line are shown in the cross sections. Adjacent segments along a line overlap, and although overlapping shotpoints have different numbers for each segment (Ackermann and others, 1994), only one of the numbers is used. A shotpoint that is used for overlapping segments is indicated by showing both segments in parentheses, such as SP1-27(A,B). Line segments are not shown (**figure 3-7**); therefore this figure should be used together with each of the velocity sections to clarify locations.

Gravity anomalies are shown on **figure 3-7** to augment the interpretation. The relation between density and seismic velocity (Christensen, 1989), combined with the wider spatial coverage of gravity, makes gravity useful to extend seismic interpretations laterally. Conversely, seismic sections provide control on the depth to density contrasts causing gravity anomalies. Gravity anomaly values discussed in the text are relative to mean gravity usually taken from the inflection point of bounding gradients. Comments on magnetic anomalies are based on the map of Cordell (1983).

Geologic relations are based on the digital geologic map. Geologic units discussed with drill hole data are shown on **table 3-3**, which correlates drill hole units to units on **Plate 1**.

Line 1 - Playas Valley

Line 1 traverses the Playas Valley from south to north (**figure 3-8**). The Cowboy Rim caldera, in the vicinity of southern Playas Valley, is part of a cluster of middle Tertiary extrusive centers in southwest New Mexico (**figure 1-6**). This cluster, including adjacent calderas in Arizona and volcanic centers in Mexico, is about 120 km in diameter and is marked by a thick, large-volume ash-flow tuff, irregular magnetic intensity, and a broad gravity low. Individually, the calderas of the cluster do not have characteristic geophysical signatures in magnetic and gravity data. Seismic lines 1, 2, and 3 cross different parts of this cluster.

In the area of Cowboy Rim caldera, SP1-02 (A) to SP1-15 (A), bedrock shows a nearly uniform velocity of about 4 km/sec throughout the penetrated depth range. This bedrock velocity indicates that volcanic rock has a thickness in excess of 1.5 km. In the valley floor north of SP1-15(A), seismic basement (about 5 km/sec) is found at varying depths ranging from less than 0.2 km to about 1.5 km. The shallower basement depths show three rises centered at SP1-19(A), SP1-33(A,B), and SP1-25(B). The first rise, which is a near vertical interface on the south, is inferred to represent the north wall of Cowboy Rim caldera; the other rises are gentle to the south and precipitous on the north, and are usually associated with west- to northwest-trending gravity highs (**figure 3-7**). These latter two rises are thought to represent parts of regional uplifts that have shallow expression beneath the valley surface. These apparent uplifts may be associated with faults of a northeast verging thrust system such proposed by Drewes (1991), or with regional compression-driven, fold-uplift systems (Woodward, 1978; Seager, 1983). Drill hole logs indicate that the basement rises are overlain by Cretaceous through Paleozoic carbonate rocks.

Line 2 - San Luis Valley through the Alamo Hueco Mountains

Starting from the east flank of the Peloncillo Mountains, line 2 (**figure 3-9**) traverses eastward across southern Animas Valley, also known as San Luis Valley, San Luis and Whitewater Mountains, southern Playas Valley, and Alamo Hueco Mountains. The velocity section shows a gap in the Playas Valley where line 2 is intersected by line 1. The velocity section shows 5 km/sec seismic basement within about 300 m of the surface over most of the San Luis and Whitewater Mountains, and the Alamo Hueco Mountains, as well as beneath bordering areas that extend into the topographic basins.

Seismic refraction data indicate that the San Luis Valley area, including the San Luis and Whitewater Mountains, are composed chiefly of volcanic strata with only a thin layer of alluvium. Seismic velocity structure indicates that the Alamo Hueco Mountains are complexly faulted. This is indicated by a step change in thickness of inferred Cretaceous sedimentary rocks [3-4 km/sec rock

between SP2-9 (E) and SP 2-13 (E)] and the disappearance of interpreted shallow Paleozoic carbonate (seismic basement 4.9-6.0 km/sec) east of SP2-11 (E). There is also a lateral seismic discontinuity centerd on SP2-19 (E) that marks a mapped normal fault separating Cretaceous sedimentary rocks on the west and Tertiary andesitic rocks on the east. The seismic change beneath SP2-19 (E) indicates a significant thickening of sedimentary or volcanic (2.9 km/sec) to the east.

Line 3 - Animas Valley

Line 3 traverses north through the Animas valley, flanked by volcanic rocks derived from calderas in the Peloncillo Mountains to the west and the southern Animas Mountains to the east (Elston, 1984; Luedke, 1993)(**figure 3-10**).

Line 3 is interpreted to show volcanic rock throughout the vertical extent of the section extending from SP3-1 through SP3-31. Within this interval, a velocity high in the lower part of layer 2, overlain by a seismically defined domed structure, suggests a volcanic center, possibly either ponded flows or an intrusion. Throughout most of velocity profile, north to SP3-31, seismic basement appears to have velocity too low (4.6-4.9 km/sec) to represent igneous, metamorphic, or dense carbonate rocks. Low gravity supports this inference.

Line 4 - San Simon Valley to the Rio Grande Valley

Seismic profile 4 (**figure 3-11**) crosses the structural grain of southwest New Mexico to provide a broad cross section of Basin-and-Range structure in the upper 1-2 km of the crust. The line is along State Highway 9 through the towns of Animas and Hachita to Columbus; from Columbus to El Paso the line follows county roads close to the Mexican border. The larger ranges traversed are west of Columbus where the elevations range from 1,280 to 1,430 m. Although the profile crosses ranges at relatively low passes, or skirts the end of ranges, the uplifted basement rock is often clearly expressed. East of Columbus, the topography is a broad plain where the elevation traversed ranges from 1,220 to 1,280 m. Outcrop is scarce east of Columbus, except across the Potrillo basalt field; nevertheless, the velocity section shows significant buried relief in the seismic basement.

In the southwest bootheel of New Mexico, seismic section 4 crosses several ranges that are composed of near-surface, high-velocity rock. Seismic basement with velocity near 5 km/sec peaks in the Animas Valley, near the town of Animas, rather than on the topographic high of the profile which occurs on a saddle between the Pyramid Mountains and the Animas Mountains. The topographic high is underlain by a several hundred meters of 2.4-3.3 km/sec rock. An upward bulge of 4.3 km/sec rock on the south edge of Muir caldera (in the Pyramid Mountains) is inferred to indicate part of the structural wall or tuff outflow pile of this caldera. A shallow northwest extension of the Little Hatchet and Sierra Rica Mountains is identified by shallow 4.7-km/sec rock

near Howell's Ridge and Coyote Hills.

Eastward of the Little Hatchet Mountains seismic rise, alluvium in Hachita Valley is inferred to be less than 300 m deep, but the Apache Hills-Cedar Range Basin has more than 500 m of 2.3 km/sec fill that is probably alluvium and conglomerate. Continuing eastward along the level terrain near the Mexican border, the thickness of the 1.7 to 2.4 km/sec alluvium varies from about 100 to 500 m. High–velocity rock occurs within a few hundred meters of the surface near the Carrizalillo Hills and the Tres Hermanas Mountains, and the broad, high-velocity (5 km/sec) subsurface expressions of these relatively small topographic rises are equivalent to those of the larger ranges found to the west. Gravity contours show that these buried ranges trend northwestward (**figure 3-7**). East of the Tres Hermanas Mountains, buried high-velocity rocks are shallow just west and east of the Potrillo Lava Field.

Seismic section 4 shows a pair of widely separated graben-like structures that are atypical in width, depth, and velocity from other Basin-and-Range structures seen in the seismic data. At both SP4-10(A) in the Animas Valley and west of the Potrillo Lava Field at SP4-8(C), seismic basement appears dropped about 1 km in narrow grabens having widths of about 5 km. These grabens have high velocity basement (6.1 km/sec) overlain by anomalously low velocity rocks that extend to near the surface. The geology in the areas of these velocity anomalies are characterized by Quaternary lavas and warm springs. These buried grabens may be Quaternary in age and probably result from volcanic rifting.

Line 5 - Peloncillo Mountains to Rio Grande Valley

Line 5 (**figure 3-12**) begins on the east flank of Peloncillo Mountains, about 40 km north of line 4, and extends east parallel to line 4 across Animas Valley and part of Pyramid Mountains, and then east to U.S. Highway 10 near the village of Separ. Near Separ, line 5 turns northeasterly and follows close to U.S. Highway 10 to the Rio Grande Valley. Except for crossing the Pyramid Mountains, this traverse crosses plains with scarce outcrop.

The central Separ Plain at SP5-34(A) is inferred to be underlain by a deep, Tertiary basin [about 2.5 km of volcanic or clastic rocks (2.3-4.0 km/sec)]. Under the western Separ plain, shallow volcanic rock at drill hole G1 and vicinity overlies a deep seismic basement uplift that probably reveals structures related to the Little Hatchet Mountains.

East of the Victorio Mountains, the seismic section indicates a wide (11 km) shelf of bedrock with velocity of 4 km/sec at depths of 300-500 m. High gravity values corroborate this (**figure 3-7**) also suggest that major parts of this structural high are buried under relatively thin cover to the east, north, and south of outcrop. Based on correlation of drill hole logs and velocity further east, the upper part of layer 2 and its overburden is probably moderately thin Quaternary alluvium and Tertiary and Cretaceous volcanic and intrusive rock overlying Paleozoic rocks; the

latter are at a depth of about 500 m. Based on this information, there is probably potential for buried mineral deposits within several hundred meters of the surface for a wide area north, south, and east of the Victorio Mountains.

Western Deming basin, extending from SP5-15(B) to SP5-19(B), partly overlies the Victorio Mountains platform. The basin is underlain by more than a kilometer of 3.7 km/sec Paleozoic rocks below 500-700 m depth. Further eastward from SP5-23(B) to SP5-31(B), the seismic section shows about 800 m of 2.4 km/sec alluvium within Deming basin.

North of Little Florida Mountains at SP5-35(B,C), seismic basement (4.5 km/sec) rises sharply by 800 m. This rise initiates a broad uplift that culminates within about 500 m of the surface at SP5-11(C) south of the Goodsight Range. Here, higher velocity seismic basement (5.2 km/sec) corresponds to high gravity that trends southeastward from Goodsight Range to East Potrillo Mountains (**figure 3-7**). There are 300-500 m of inferred volcanic rock (3-4 km/sec) overlying this rise that are probably equivalent to outcrops in the Goodsight Range.

Uplift of the Good Sight Range terminates eastward at SP5-20(C) where seismic basement deepens to about 1,200–m depth. Inferred faulting in Rio Grande Valley drops seismic basement to more than 2,500–m depth near the east terminus of the refraction section.

Line 7 - Tres Hermanas Mountains through the Deming Basin

Line 7 traverses from south to north making a broad curve to the west around Tres Hermanas Mountains (southwest of Florida Mountains), then continues north across the Deming basin to the vicinity of Cookes Range (**figure 3-13**).

East of the Tres Hermanas Mountains, 4.3 km/sec rock, inferred to be carbonate rock, is within 500 m of surface. North of the Tres Hermanas Range, 300 m of alluvium and volcanic rock (2.4-2.8 km/sec) are indicated. Further northward under a flat plain west of the Florida Mountains at SP7-29(A), seismic basement (5.2 km/sec) is less than 100 m from the surface. A one-km–thick section of inferred carbonate rocks (4 km/sec) overlies seismic basement northward from SP7-29(A,B) to SP7-12(B). A northwest-trending gravity high over this structure connects Paleozoic outcrop in the Little Florida Mountains to similar outcrop in Red Mountain (**figure 3-7**).

Line 7 corroborates line 5 in showing a major basin in the Deming area where seismic basement is at 1.5- to 2.0-km depth and bedrock (3-4 km/sec) is 500-600 m beneath alluvium (2.6-2.9 km/sec). Northward, as line 5 approaches Cookes Range, 4-km/sec rock (Paleozoic/Mesozoic carbonate rock or Tertiary volcanic/sedimentary rock) rises to within 300 m of the surface.

CONCLUSIONS—IMPLICATIONS FOR RESOURCE ASSESSMENT

Seismic velocity sections provide insight into the structure, lithology and associated resources beneath basins and mountain ranges in southwest New Mexico. Based on drill hole correlations, velocity structure to a depth of 2-3 km, in most cases, predicts the depth to major lithologic interfaces with an accuracy of 20 to 25 percent. Correspondence of gravity highs to areas of inferred uplift and gravity lows to areas of deep seismic basement indicates that gravity may be used to extend the seismic interpretation outward from the seismic survey lines.

Beneath a thin, dry, surface zone (0.85 km/sec), there are three main seismic horizons in the seismic profiles: (1) a wet, alluvial layer (1.6-3.0 km/sec), (2) a layer of mixed sedimentary and volcanic lithologies (2.7-4.5 km/sec), and (3) seismic basement (4.0 to 6.1 km/sec). Across the ranges, layers 1 and 2 may be attenuated or disappear. The second horizon is composed of 2 to 3 seismic layers that show horizontal and vertical variations in clastic sedimentary rock, volcanic rock, and porous, impure limestones. Seismic basement is mostly compact Paleozoic carbonate rock; igneous intrusive rock may be locally present.

Figure 3-14 shows the location of major geologic elements in the subsurface revealed in the seismic data: (1) thick alluvial deposits: areas inferred to be underlain by more than 300 m of Quaternary alluvium (less than 3 km/sec), (2) thick volcanic deposits: areas underlain by more than one km of inferred volcanic rock (3.5-4.5 km/sec), (3) shallow Mesozoic and Paleozoic rock: areas of uplift where shallow Mesozoic or Paleozoic rock (3-5 km/sec) are interpreted to be within 500 m the surface, (4) basins: areas where seismic basement is overlain by more than a kilometer of inferred carbonate rocks (4-5 km/sec), and (5) basalt-related grabens: areas where narrow, volcanic-associated grabens are interpreted as likely Quaternary basaltic rift zones.

Areas of inferred thick volcanic rock are located in the bootheel region of New Mexico where a cluster of mid-Tertiary volcanic centers is known from geologic mapping. Seismic data in the southern Animas Valley are interpreted to indicate that a caldera structure extends beneath valley fill. This information allows extension of possible areas for volcanic-hosted epithermal deposits.

Major basins interpreted from the seismic data show inferred alluvial deposits (layer 1) ranging in thickness from 200 to 600 m, overlaying a thick section of layer 2 rock. Areas where the thickness of alluvial deposits approached 500 m or more are indicated on **figure 3-14**. Seismic basement (either geologic basement or, more likely, Paleozoic carbonate sequences) is 1-2 km depth in these basins. These basins contain potential water resources in the alluvial layer--the upper part of layer 2 where velocities are less than about 3 km/sec. Basins are generally non-exploitable for mineral resources because of the thick overburden that covers any rock having the potential to be mineralized.

There are areas of probable uplift where the depth to Mesozoic and Paleozoic rock (4-5 km/sec) is less than 700 m. In a few localities, high-velocity rock is modeled at a depth of 100-200 m. Gravity links the inferred uplifts to bordering ranges at distances of few tens of kilometers. Interpretation of the lithology (Mesozoic or Paleozoic carbonate rock) is based on correlation of refracting interfaces and velocities with outcrop or drill hole logs. Intrusions are possible in these rocks, but are not easily distinguished in the seismic data. Under favorable economic circumstances, these areas may be explored for a variety of mineral deposits, including carbonate-hosted veins, skarns, and porphyry deposits. Analysis of auxiliary data (i.e., geochemical data, surface electrical surveys, and aeromagnetic maps) that have the potential to define possible plutons, associated mineralization, and alteration, will be crucial to define areas where exploration for and development of buried ore deposits may be likely and economical.

There is potential for petroleum resources in the basin areas, as well (Thompson and others, 1978; Thompson, 1981). A compilation of recent conclusions on the prospects for petroleum resources in the study area is in Bartsch-Winkler (this volume).

Along line 4, two seismic structures indicated narrow zones of deep, high-velocity seismic basement overlain by low seismic velocities upward through layer 1. The areas are highlighted by gravity lows. Both areas adjoin Quaternary volcanic rocks, and are near known geothermal areas. These structures are interpreted as Quaternary grabens or rifts, and it is possible that these structures are related to fairly recent (2-5 Ma) deep crustal faulting and associated crustal melting. The structures may form paths for present–day upwelling of thermal waters (see Duffield and Priest, this volume).

AERIAL GAMMA-RAY RADIOACTIVITY

by

James A. Pitkin

INTRODUCTION

Aerial gamma-ray radioactivity data for the Mimbres Resource Area consists of spectrometer surveys flown during the U.S. Department of Energy National Uranium Resource Evaluation (NURE) program (1974-1983). NURE surveys that include parts of the study area are those for the Clifton (Texas Instruments, Inc., 1979), Douglas (Texas Instruments, Inc., 1979), El Paso (Carson Helicopters, Inc., 1981), Las Cruces (Carson Helicopters, Inc., 1981), Tularosa (Geodata International, Inc., 1979), and Silver City (Texas Instruments, Inc., 1979) 2° quadrangles. Aerial gamma-ray data (aeroradioactivity) from these surveys were used to prepare an aeroradioactivity database for the study area. Other compilations of NURE data that include the study area are Duval and others (1995) and Phillips and others (1993).

Aeroradioactivity is the measurement of terrestrial radioactivity with instruments operated in low-flying aircraft. The source of the radioactivity measured is the near-surface rock-and-soil (to 12-in depth) where the primary gamma-ray emitting isotopes are from the natural radioelements potassium (K), uranium (U), and thorium (Th). NURE aerial systems were quantitatively calibrated at sites of known radioelement concentrations, permitting quantitative reporting of survey data in percent (%) for K and parts per million (ppm) for U and Th (assuming equilibrium in the respective decay series). The near-surface distribution of K, U, and Th generally reflects bedrock lithology and modifications due to weathering, erosion, transportation, ground water movement, and hydrothermal alteration. Common rock types readily discriminated by aeroradioactivity measurements include more radioactive (greater concentrations of radioactive minerals) felsic igneous rocks, arkosic sandstones, and most shales, and less radioactive (lesser concentrations) mafic igneous rocks, (clean) quartzose sandstones, and most limestones.

Aerial flight-line spacing for the Mimbres Resource Area database is 3-mi east-west and 12-mi north-south. A minimum-curvature algorithm (Webring, 1981) was applied to the flight line data, producing K, U, and Th 1.8-mi^2 grids, which comprise the study area database. The grids were used to prepare K, U, and Th color and black-and-white maps at 1:250,000- and 1:500,000-scales for use in the assessment process and grey-scale maps at 1:1,000,000-scale for inclusion in this report. Grids of the ratios U:K, U:Th, and K:Th were also prepared and maps were made at the several scales.

DISCUSSION

K, U, Th, U:K, U:Th, and K:Th aeroradioactivity contour maps of the study area are shown (respectively) in **figure 3-15, figure 3-16, figure 3-17, figure 3-18, figure 3-19, and figure 3-20**. The boundary is shown on each map and geographic locations shown on the maps are described in figure titles.

The near-surface distribution patterns of K, U, and Th as displayed by aeroradioactivity maps are often similar, resulting from common rock-type associations for these elements. However, discontinuities in the patterns can reflect significant mineralogic discontinuities, such as the contrasting properties of felsic and mafic igneous rocks. Because thorium is the least mobile of the elements, it generally has a more consistent distribution pattern than K or U. Thus, Th is used as the stable denominator in U:Th and K:Th ratios, thereby highlighting subtle variations in U and K distribution. Of particular interest are variations from the U:Th 0.25 ratio on **figure 3-19**. While the crustal ratio of U:Th ranges from 1:2 to 1:8 (Hoover, Heran, and Hill, 1992), the value of 1:4 (0.25) has been chosen arbitrarily for use in the following interpretive discussion. During interpretation, it is suggested that values greater than 0.25 may indicate relative enrichment of U, and values less than 0.25 may indicate relative depletion of U. The U:K ratio is also shown in map

form because of possible lithologic and (or) alteration significance.

INTERPRETATION

Natural radioelement distribution for the study area, as demonstrated in the contour maps, has a diverse pattern that reflects the varied and complex geology. The Basin and Range physiographic province, which includes most of the study area, has a complex radioelement pattern that occasionally reflects the north-northwest trending horst-and-graben structures of the province. The tectonic activity that formed the province began more than 20 m.y. ago (see Bartsch-Winkler, this volume) and geologic processes have subsequently modified the radioactive mineral distribution in the near-surface rock and soil. Nonetheless, geologic features with distinct radioelement character occur in the area as do a number of aeroradioactivity linear trends, which demonstrate the occurrence of geologic features with radioelement lithologic continuity.

Radioelement features that are coincident relative highs of all three radioelements most often reflect the presence of felsic igneous rocks or of similar radioelement lithologies. Such features occur in the Basin and Range part of the study area, and are even more common in the Mogollon-Datil volcanic field (**figure 1-5, figure 1-6**). Other areas of coincident higher radioelement values include felsic igneous rocks in part of the Burro Uplift on the west side and in parts of the Organ and Doña Ana Mountains on the east side, and in south-central Luna County, south of Deming, where feature sources are a combination of felsic bedrock in the Florida and Tres Hermanas Mountains and possible felsic detritus in adjacent basins. Radioelement ratios for areas of three-element coincident features are often featureless in these areas, reflecting similar distribution patterns of ratio components.

The aeroradioactivity feature of relatively higher values that includes part of the Burro Uplift is in the west-central part of the study area, in northern Hidalgo County and adjacent southern Grant County. This distinct feature is mostly higher K values (2.6-3.4%) with associated but less common higher U (2.6-3.2 ppm) Th (10-13 ppm), has predicable positive K:Th expression, and is within an area roughly bounded by Silver City, Deming, and Lordsburg. Noncoincident aeroradioactivity features are actually more common than coincident features, demonstrating varying radioelement lithologies and considerable variation in geologic sources. Geologic sources for the K feature include Proterozoic metamorphic and metaigneous rocks, Laramide intrusive rocks, Tertiary rhyolites and other volcanic rocks, and Tertiary and Quaternary alluvial and pediment deposits. Radioelement relative highs associated with surficial detrital deposits can reflect derivation of the detritus from more radioactive (possibly felsic) rocks in nearby ranges.

Another distinct relatively higher aeroradioactivity feature occurs in south-central Luna County, at and south of Deming, where higher Th (10-13 ppm), K (2.8-3.4%), and U (2.6-3

ppm) concentrations include the Florida and Tres Hermanas Mountains. This area of dominant Th and K and associated U has many non-coincident radioelement features, indicating varied lithologic sources. Geologic units present include Proterozoic metamorphic and metaigneous rocks, Tertiary igneous rocks, and Quaternary alluvial and pediment deposits. Radioelement ratio features include areas of higher U:Th (0.39) and K:Th southwest of Deming that include the Victorio Mountains and an area of higher K:Th southeast of Deming that include the east-central part of the Florida Mountains. Distinct higher radioelement values also occur north of Deming, along and within the southern part of the Mogollon-Datil volcanic field, mostly outside of the study area. Cookes Range north of Deming (and within the Mimbres Resource Area) has distinct lower values of 1-1.6% K, 1.2-1.6 ppm U, and 5-7 ppm Th, and higher U:K and lower K:Th that relate to the Paleozoic and Mesozoic carbonate sedimentary rocks that occur in the Range.

The eastern part of the study area in Doña Ana County includes a number of distinct aeroradioactivity features. East of Las Cruces, a sizeable area of coincident higher values (2.4-3.2% K, 2.8-3.2 ppm U, 10-13 ppm Th) is centered on Tertiary felsic intrusive rocks in the Organ Mountains and extends outward into piedmont alluvial deposits. North of Las Cruces, a smaller area of coincident values most prominent in U (2.6-2.8 ppm) and with K (2.4-2.8%) and Th (10-11 ppm) expression has as geologic sources the Tertiary felsic igneous rocks of the Doña Ana-Dagger Flat calderas and adjacent alluvial deposits. Northwest of Las Cruces, two north-northeast–trending linear features, each 30 to 40 km in length, are best expressed in Th (10-12 ppm) with associated K (2.4-2.8%) and U (2.6-2.8 ppm) and with U:Th lows (<0.27); these occur in the Rough and Ready Hills and along the east side of the Sierra de las Uvas. They have geologic sources in Tertiary igneous rocks and alluvial deposits. A discontinuous series of U relative highs (2.8-3.2 ppm) occurs in the Rio Grande Valley southeast and northwest of Las Cruces. To the southeast, a prominent U feature has slight Th expression (8-10 ppm) and an alluvial deposit source. To the northwest are three distinct U relative highs, which have, variably, Permian sedimentary rocks, Tertiary igneous rocks, and Quaternary deposit sources. These U features all have prominent expression in the U:K and U:Th (>0.39) ratios.

Distinct aeroradioactivity lows occur in the southeast part of the study area, in southern Doña Ana County. Relatively low values of 1.4-2 ppm U and 5-6 ppm Th and moderate values of 1.6-2.2% K characterize Upper Santa Fe Group sedimentary rocks to the east and Quaternary gypsiferous eolian deposits and mafic volcanic rocks of the West Potrillo Mountains to the west. Distinct K:Th highs and U:K lows confirm the radioelement associations. Between Kilborne Hole and the Texas state line, a lower U (1-1.4 ppm) and Th (4-5 ppm) feature occurs, owing to the presence of Upper Santa Fe Group rocks. In this area, K distribution is featureless, but the K:Th ratio includes a sizeable area of higher values that is controlled by the low Th. A small but distinct

K low (1.2-1.6%) with associated low Th (4-5 ppm) and no U expression occurs in the East Potrillo Mountains, reflecting low-radioelement-concentration Paleozoic and Mesozoic sedimentary rocks. This feature also has a small but distinct U:Th expression (>0.39) that is not apparent in the U or Th data, illustrating the value of the ratios.

A K-dominant radioelement feature extends across the study area for some 150-km at about N60°W as it follows major trends of the Basin and Range. The feature, herein named the Mangus trend, on its south end extends from the west side of the Tres Hermanas Mountains northwest through the Burro Uplift, follows a drainage divide between the Big Burro Mountains and the Little Burro Mountains, and continues to the northwest along the west side of Mangus Valley. Mangus trend is characterized by relatively higher concentrations of K (2.8-3.4%) for much of its linear extent, and higher values of U (2.6-3.2 ppm) and Th (10-13 ppm) for the White Signal district in the Burro Uplift and for Mangus Valley. The U and Th data show subdued linear trends of relatively moderate values (2-2.4 ppm and 8-10 ppm, respectively) that follow the Mangus trend in the southeast part of the Burro Uplift. Radioelement ratios show no expression of this feature. The Mangus trend seemingly is controlled by mapped faults of relatively short dimension (<20 km) south of Interstate 10, and frequently follows topographic features, possibly fault controlled, north of the highway. Geologic source rocks include probable felsic volcanic rocks in the Tres Hermanas Mountains, alluvial and pediment deposits to the northwest, felsic rocks in the Burro Uplift that include Proterozoic metamorphic and metaigneous rocks, Laramide granites and Tertiary volcanic rocks, and Tertiary and Quaternary detrital deposits in Mangus Valley.

The "bootheel" area is within the Mogollon-Datil volcanic field; however, the relatively abundant calderas, caldera-related structures, and felsic igneous rocks are only on occasion prominent as areas of higher radioelement values because of subsequent geologic processes that modified volcanic field near-surface lithologic characteristics. A volcanic structure is apparent in the aeroradioactivity data at the southwest side of the "bootheel," in the southern Peloncillo Mountains, where a prominent Th oval feature of relatively higher values of 10-13 ppm encloses a central low of 7-9 ppm that extends into Arizona. This central low coincides with the mapped outline of the Rodeo caldera. The sizeable exterior high includes parts of the Animas Peak and Tullous calderas as the feature extends eastward across Animas Valley into the Animas Mountains, and southward to include part of the Germonio Trail caldera (**figure 1-6**). Geologic sources include felsic volcanic rocks and alluvial and pediment deposits with varying quantities of felsic detritus. U (2.4-3.4 ppm) and K (2.2-3.4%) values for the area of the Th feature vary considerably, but it is possible to observe that, compared to the Th data, the U data has generally similar patterns and the K data has generally dissimilar patterns, demonstrating differing lithologies. The U:Th ratio generally is relatively low (<0.27), again demonstrating the relative

dominance of Th. At the U.S.-Mexico border west of Antelope Wells, coincident higher Th (10-13 ppm) and U (2.6-3 ppm), less prominent K (2.6-3%), and resulting lower K:Th reflect another felsic volcanic rock feature, the northern part of the San Luis caldera. The most prominent three-element coincident feature in the "bootheel" is at the southeast tip of the Little Hatchet Mountains, as indicated by higher values of 2.4-3.2% K, 2.4-3.2 ppm U, and 9-12 ppm Th. Proterozoic granite crops out at the south end of the Mountains and is an immediate felsic explanation for the feature. The feature extends into pediment to the southeast, correlates with a remote sensing iron oxide feature, and geochemical analyses of geologic samples from this area show measurable Ag and other metals (M.L. Silberman, oral commun., 1994), possibly indicating the occurrence of hydrothermal alteration.

Aeroradioactivity data for the east side of the "bootheel" include three-element lows of large areal extent; these result from Paleozoic and Mesozoic sedimentary rocks, mostly limestones and dolomites, that are present in the Sierra Rica and Big Hatchet Mountains. For these areas, K values are 0.6-1.4%, U is 1-1.4 and 1.4-2 ppm, and Th is 2-5 ppm. The area that includes the Sierra Rica has relatively low U of 1-1.4 ppm and no ratio expression, the area that includes the Big Hatchets has slightly higher U of 1.4-2 ppm and distinct higher U:K and U:Th (>0.39) values. Other areas in the "bootheel" with associated distinct aeroradioactivity lows (1.2-1.6% K, 1.4-1.8 ppm U, 4-6 ppm Th) include the central Little Hatchet Mountains and the pediment to the west, the north end of the Animas Mountains, and the McGhee Peak district in the Peloncillo Mountains south of Interstate 10, all occurrences of Paleozoic and Mesozoic carbonate sedimentary rocks. These areas are most distinct in the K and somewhat in the U data, as the Th data includes large areas of low values (generally <6 ppm) that are appreciably larger than the areas of exposed carbonate rocks. Several relatively small outcrops of carbonate rocks in the central Animas Mountains also are aeroradioactivity lows, however best identified at map scales larger than 1:1,000,000. Other notable features in the "bootheel" include three distinct K:Th features where K is appreciably enhanced relative to Th. These features occur in Playas Valley west of the southern Little Hatchet Mountains where the geologic source is pediment and alluvial deposits; in the Hatchita Valley just west of the Sierra Rica where the source is pediment and alluvial deposits; in the northeast part of the Little Hatchet Mountains where the source is Cretaceous carbonate sedimentary rocks and Tertiary volcanic rocks.

The Burro Uplift aeroradioactivity feature of variably higher values includes linear features that are parallel to or are normal to the northeast-trending Santa Rita lineament (see Bartsch-Winkler, this volume; **figure 1-4**). The K-distinctive Mangus linear feature crosses the eastern part of the Uplift feature, trends normal to the lineament, and has an appreciably longer dimension than all other trend features discussed here. Northwest of Lordsburg, a U linear is

controlled by isolated but prominent values (2.6-3.2 ppm) that trend about N75°E, approximate the trend of the lineament zone, and terminate at the Mangus trend. Geologic sources are Proterozoic and Tertiary felsic igneous rocks and Quaternary pediment and alluvial deposits. Southeast of Lordsburg, another U linear (2.6-3.2 ppm) trend follows the lineament at N65°E as it extends from the Peloncillo Mountains through the Pyramid Mountains towards the Burro Uplift as it apparently terminates near Interstate 10. Geologic sources are mostly Tertiary felsic igneous rocks and Quaternary pediment and alluvial deposits. The Th data includes three linear features (10-13 ppm) within the described area that are west of and parallel to the Mangus feature; the two to the northeast have Proterozoic and Tertiary felsic igneous rock sources, the one to the southwest has a pediment and alluvial deposit source. All linears - K, U, Th - usually have associated higher values of one or both of the other radioelements, but are most evident in the specific radioelement. Ratios generally show slight expression of the above-described linear features; a minor exception is linears of low K:Th values that correspond to the three Th linears.

In eastern Grant County, northeast of the Burro Uplift and of the Mangus linear, is a varied pattern of aeroradioactivity relative highs and lows. Higher values are mostly from felsic source rocks, a combination of Laramide and Tertiary volcanic and plutonic rocks especially within the Mogollon-Datil volcanic field, while lower values are mostly from Paleozoic carbonate sedimentary rocks in and around the Silver City and Santa Rita mining districts and from scattered Tertiary intermediate-composition volcanic rock exposures. Higher K values vary appreciably, from 2-2.6% for less felsic or intermediate sources and from 2.6 to 3.2 % for felsic sources. Higher U values also vary, from 1.8-2.6 ppm for intermediate sources, and from 2.6-3.2 ppm for more felsic rocks. Th varies from 8-10 ppm for intermediate rocks to 10-14 ppm for volcanic and plutonic felsic rocks in northern and northeastern Grant County. Ratios are frequently not distinctive, the consequence of similar radioelement distribution patterns.

Lower aeroradioactivity values in the area of the Silver City and Santa Rita districts are very distinctive for Paleozoic carbonate sedimentary rocks. K values of 0.5-1.4% indicate these outcrops, while U values of 0.8-1.4 ppm and Th values of 3-6 ppm occupy larger areas that include these rocks. Localized higher values of U:K and U:Th (>0.39) in the Santa Rita district denote the sedimentary rocks, as do less prominent ratio values to the southeast and northwest of Silver City. Another ratio feature is large areas of higher K:Th around Silver City, resulting from low Th, that exclude the sedimentary rocks and include mostly Quaternary deposit and some Tertiary igneous rock geologic sources.

As discussed in this interpretation, K values generally <1.4% throughout the Mimbres Resource Area are a direct indicator for the occurrence of carbonate sedimentary rocks, mostly Paleozoic and Mesozoic in age. Specific localities discussed include the Cookes Range north of

Deming, the East Potrillo Mountains in southeast Doña Ana County, the Sierra Rica, the Big Hatchet Mountains, and other localities in the southwest part of the study area (including the "bootheel"), and in the Silver City and Santa Rita districts. For areas of low K values, U and Th values also are relatively low, although the low Th values often include an area larger than that of the low K values. A number of these areas of low K and Th include several levels of U values, both relatively low and relatively moderate, examples being the Sierra Rica and the Big Hatchet Mountains. These and other areas of moderate U, low K, and low Th will and do have distinct expression in the U:K and U:Th ratios. To investigate any mineral deposit significance of these aeroradioactivity features, a mining district map for the area was compared (at 1:500,000 scale) with the K, U:K, and U:Th maps. Results show that each of the localities listed above includes a mining district, low K values, and commonly distinctly positive U:K and(or) U:Th ratios. Those localities (Silver City, Rincon, Gillespie) without distinct ratio expression have a less pronounced expression. Further investigation, including examination of geochemical data and profiling of the aeroradioactivity data at larger (1:24,000) scales, is needed to determine any possible mineral deposit significance of the aeroradioactivity features.

GEOLOGY OF INDIVIDUAL MOUNTAIN RANGES WITHIN THE MIMBRES RESOURCE AREA

by

Susan Bartsch-Winkler, USGS

***with sections on* the Summit and Big Lue Mountains, San Francisco Canyon, and Mule Creek areas**

by V.T. McLemore, NMBMMR

Mountain ranges of nearly all of the Mimbres Resource Area, except those on the southern Mogollon volcanic plateau in Grant County, are generally north-south trending, scattered fault blocks separated by intermontane valley grabens, many of which contain rivers and playa deposits. The stratigraphy varies from range to range, due to the effects of uplift and erosion, stratigraphic pinch-outs, normal and thrust faulting, tilting, and intrusion and volcanism, mainly during Laramide and Basin and Range tectonic events. The ranges are typically composed of Paleozoic sedimentary strata, mostly of limestone, dolomite, shale, and sandstone; many have basement Precambrian igneous and metamorphic cores. Marine shelf deposits are characteristic of Paleozoic rocks, with hiatuses that probably represent periods of uplift and erosion. Early Mesozoic (Triassic and Jurassic) rocks are generally absent in the study area owing to an extended period of non-deposition. Development of basins in late Mesozoic time in parts of the study area is evidenced by thick sections of Cretaceous sedimentary rock. These layered rocks are locally intruded by Mesozoic and Cenozoic plutons and interbedded with, or buried beneath, volcanic debris and volcaniclastic rocks. Many of the rocks were metamorphosed and mineralized by igneous and volcanic activity during Mesozoic and Cenozoic times.

The following is a generalized summary of the geologic setting of many of the mountain ranges, listed alphabetically by county) (**figure 1-1**).

GRANT COUNTY

Silver City is the largest community in Grant County, which is traversed by the Gila and Mimbres Rivers. Gila Wilderness Area has been under protection from mineral entry since its formation in 1924. Aldo Leopold Wilderness Area was established in 1980. Much of the county is in the Gila National Forest. Gila Cliff Dwellings National Park lies adjacent to the study area boundary.

BLACK RANGE/MIMBRES MOUNTAINS (GRANT COUNTY)

The Black Range-Mimbres Mountains areas within the study area are located along the northern boundary of Grant County.

General Geology

In the Black Range and Mimbres Mountains areas, Precambrian and Paleozoic units are overlain by volcaniclastic deposits of the Eocene and Oligocene Rubio Peak Formation and the Oligocene Kneeling Nun Tuff (see appendix B)(Ericksen and Leland, 1984; Ericksen and Wedow, 1976; Ericksen and others, 1970; Jicha, 1954). West of the Mimbres River, Late Cretaceous and early Tertiary andesite unconformably overlies the Paleozoic and Cretaceous sedimentary rocks. On the east side of the range, similar rocks are intruded by a 73 m.y.-old [Late Cretaceous); Hedlund, 1974] monzonite stock. North-south-trending Emory caldera (McDowell, 1971), the major geologic feature of these ranges, is located in the Black Range-Mimbres Mountains in Sierra and Grant Counties (**figure 1-6**). Emory caldera is the source of the Kneeling Nun Tuff (Oligocene, 33.4 m.y.; McDowell, 1971; Elston and others, 1975). Uplift occurred on the Emory caldera during formation of the resurgent dome and after eruption of the Kneeling Nun Tuff and early extensional faulting. The uplift exposed Precambrian and Paleozoic rocks that underlie the caldera and resurgent dome.

The Kneeling Nun Tuff is 488-1,007 m thick, and reveals the variation in stratigraphic thickness of the Kneeling Nun and the extent of the caldera. The resurgent dome that nearly fills the central caldera is 55 km x 26 km and elongate in northerly direction parallel to the structure of the Black Range. Ring and radiating fractures extend 26 km from the margin of the caldera. Xenoliths (inclusions) of Rubio Peak andesite and brecciated zones occur within the Kneeling Nun Tuff locally, and may form part of the vent zone of the Emory caldera. The outflow facies of the Kneeling Nun Tuff (99-153 m thick) extends for at least 29 km from the caldera margin. The 34-m.y.-old Fall Canyon Tuff (Ratté and Gaskill, 1975) may also originate in the Emory caldera (Ratté and others, 1984).

The Mimbres Peak Formation forms moat and ring-fracture deposits laid down after formation of the resurgent dome. The formation is highly variable in composition and thickness, consisting of rhyolitic pumiceous basal tuff overlain by flow-banded rhyolite. On the eastern margin, andesite flows are interbedded with moat deposits. Although highly variable, deposits generally thin away from the caldera margin. Pollack Quartz Latite, a porphyritic unit, forms dome complexes and underlies much of the crest of the Black Range north of Emory Pass. Rhyolite porphyry, locally pegmatitic (containing coarse-grained crystals that probably form within magma deep in the crust), forms north-trending dikes that transect the Kneeling Nun Tuff on the crest and the western boundary fault of the resurgent dome. The dikes may have been emplaced during resurgence. Base-metal mineralization occurs adjacent to the western boundary fault in Paleozoic carbonate, and is probably related to intrusion of the rhyolite porphyry (D.C. Hedlund, personal

commun., *in* Elston and others, 1975).

The resurgent dome and horst were not buried by later volcanic deposits, but surrounding rocks were. Basaltic andesite flows (Razorback Formation and Bear Springs Basalt) overlie the Emory caldera. Rhyolitic rocks equivalent to those of the Mogollon Plateau are missing from the area. Caldera flanks were buried under Gila/Santa Fe Group deposits, including basalt flows, and underlie Quaternary terrace and pediment deposits and younger basalt flows.

Mineral Resources

Carpenter mining district is in the Mimbres Mountains. Base-metal mineralization (lead, zinc, copper, and silver) is present locally along faults in Paleozoic carbonate rocks adjacent to intrusive rocks. Kaolin clay, perlite, moonstone (Rabb Park, Black Range Primitive Area), topaz (Round Mountain, Black Range Primitive Area), and tin deposits occur in the Datil Formation in Sierra County northeast and east of the Mimbres Resource Area (Ericksen and others, 1970).

References

(* reference used in writing above summary)

Correa, B.P., 1980, Fluorine and lithophile element mineralization in the Black Range and Sierra Cuchillo, New Mexico, *in* Burt, D.M., Sheridan, M.F., Bikun, J., Christiansen, E., Correa, B.P., Murphy, B., and Self, S., ed., Uranium mineralization in fluorine-enriched volcanic rocks--Final report: GJBX-225-80, p. 459-494.

Drewes, Harald, Houser, B.B., Hedlund, D.C., Richter, D.Y., Thorman, C.H., and Finnell, T.L., 1985, Geologic map of the Silver City 1° x 2° quadrangle, New Mexico and Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map I-1310-C, scale 1:125,000.

Duffield, W.A., 1987, Relations between cassiterite-bearing veins and rhyolite lavas, Black Range area, southwestern New Mexico, *in* Sachs, J.S., ed., USGS Research on Mineral Resources, 1987, Program and Abstracts: U.S. Geological Survey Circular 995, p. 16-17.

Eggleston, T.L., and Norman, D.I., 1983, Tin mineralization in Taylor Creek Rhyolite, Black Range, New Mexico: New Mexico Geology, v. 5, no. 3, p. 66.

Eggleston, T.L., and Norman, D.I., 1987, New isotopic dates for the Taylor Creek Rhyolite and associated rocks in the Black Range of New Mexico: Isochron/West, no. 48, p. 23-25.

*Elston, W.E., Seager, W.R., and Clemons, R.E., 1975, Emory cauldron, Black Range, New Mexico: Source of Kneeling Nun Tuff, *in* Seager, W.R., Clemons, R.E., and Callender, J.F., eds., Guidebook of the Las Cruces Country: New Mexico Geological Society, 26th Annual Field Conference, p. 283-292.

*Ericksen, G.E., and Leland, G.R., 1984, Black Range Primitive Area, New Mexico, *in* Marsh, S.P., Kropschot, S.J., and Dickinson, R.G., eds., Wilderness mineral potential; assessment of mineral resource potential in U.S. Forest Service lands studied 1964-1984: U.S. Geological Survey Professional Paper 1300, p. 795-797.

*Ericksen, G.E., and Wedow, H., Jr., 1976, Tertiary extrusive sheets and related intrusions in the Black Range, New Mexico, *in* Elston, W.E., and Northrop, S.A., eds., Cenozoic volcanism in southwestern New Mexico: New Mexico Geological Society Special Publication 5, p. 63-67.

*Ericksen, G.E., Wedow, H., Jr., Eaton, G.P., and Leland, G.R., 1970, Mineral resources of the Black Range Primitive Area, Grant, Sierra, and Catron Counties, New Mexico: U.S. Geological Survey Bulletin 1319-E, 162 p.

Farris, S.R., 1981, Geology and mid-Tertiary volcanism of the McKnight Canyon area, Black Range, Grant County, New Mexico: Albuquerque, University of New Mexico, unpublished M.S. thesis, 87 p.

Fodor, R.V., 1975, Petrology of basalt and andesite of the Black Range, New Mexico: Geological Society of America Bulletin, v, 86, p. 295-304.

Fodor, R.V., 1978, Ultramafic and mafic inclusions and megacrysts in Pliocene basalt, Black Range, New Mexico: Geological Society of America Bulletin, v. 89, no. 3, p. 451-459.

Fries, Carl, Jr., 1940, Tin deposits of the Black Range, Catron and Sierra Counties, New Mexico--A preliminary report [abs.]: American Geophysical Union Transactions, 21st annual meeting, pt. 1, p. 362.

Fries, Carl, Jr., and Butler, A. P., 1940, Geologic map of the Black Range tin district, New Mexico: U.S. Geological Survey Strategic Minerals Investigations Preliminary Map, scale 1:62,500.

Harrison, R.W., 1990, Cenozoic stratigraphy, structure, and epithermal mineralization of the north-central Black Range, New Mexico, in the regional geologic framework of south-central New Mexico: Socorro, New Mexico Institute of Mining and Technology, Ph.D. Dissertation, 525 p.

Harrison, R.W., Dymek, R.F., and Shelton, K.L., 1989, Early Tertiary wrench-fault tectonics along the eastern flank of the Black Range, southwestern New Mexico [abs.]: Geological Society of America Annual Meeting, Abstracts with Programs, v. 21, no. 6, p. 203.

Heyl, A.V., 1983b, Some mineral localities in the Black Range and vicinity, south-central New Mexico [abs.]: Abstracts; New Mexico mineral symposium, unpaginated.

Heyl, A.V., 1990, Minerals of the Black Range and vicinity, southwest New Mexico [abs.]: New

Mexico mineral symposium, p. 31. [Also New Mexico Geology, v. 12, no. 2, p. 31.]
*Jicha, H.L., Jr., 1954, Geology and mineral resources of Lake Valley quadrangle, Grant, Luna, and Sierra Counties, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 37, 93 p.
Kuellmer, F.J., 1954, Geologic section of the Black Range west of Kingston, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 33, 100 p.
Kuellmer, F.J., 1956, Geologic map of Hillsboro Peak 30' quadrangle: New Mexico Bureau of Mines and Mineral Resources Geologic Map 1, scale 1:126,720.
Lawrence, V.A., 1986, Developments in the Cenozoic volcanic stratigraphy of the Indian Peaks area, northern Black Range, New Mexico, *in* Clemons, R.E., King, W.E., and Mack, G.H., eds., Truth or Consequences Region: New Mexico Geological Society, 37th Annual Field Conference, Guidebook, p. 179–182.
Lucas, S.G., 1986, Oligocene mammals from the Black Range, southwestern New Mexico, *in* Clemons, R.E., King, W.E., and Mack, G.H., eds., Truth or Consequences region: New Mexico Geological Society, 37th Field Conference, Guidebook, p. 261-263.
Lufkin, J.L., 1972, Tin mineralization within rhyolite flow-domes (Tertiary), Black Range, New Mexico: Palo Alto, Calif., Stanford University, unpublished Ph. D. dissertation, 227 p.
Lufkin, J.L., 1976, Oxide minerals in miarolitic rhyolite, Black Range, New Mexico: American Mineralogist, v. 61, nos. 5-6, p. 425-430.
Maxwell, C.H., Foord, E.E., Oakman, M.R., and Harvey, D.B., 1986, Tin deposits in the Black Range tin district, *in* Clemons, R.E., King, W.E., and Mack, G.H., eds., Truth or Consequences region: New Mexico Geological Society, 37th Field Conference, Guidebook, p. 273-281.
*McIntosh, W.C., Chapin, C.E., Ratté, J.C., and Sutter, J.F., 1992, Time-stratigraphic framework for the Eocene-Oligocene Mogollon-Datil volcanic field, southwest New Mexico: Geological Society of America Bulletin, v. 104, p. 851-871.
Murphy, M.O., 1964, Moonstone of the Black Range, New Mexico: Lapidary Journal, v. 18, no. 1, p. 144-153.
Richter, D.H., and Lawrence, V.A., 1983, Mineral deposit map of the Silver City 1° x 2° quadrangle, New Mexico and Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map I-1310-B, 70 p.

BIG BURRO MOUNTAINS; LITTLE BURRO MOUNTAINS

Big Burro Mountains, a northwest-trending fault block that is partly tilted to the northeast, is located in central Grant County west of Silver City. Big Burro Mountains comprise part of the

Burro Mountains uplift, which is underlain by and contains the largest exposures of Precambrian basement rocks in southwestern New Mexico (**figure 1-4**). The mountain range is characterized by post-Laramide block faulting resulting in the formation of at least three separate northwest–trending blocks composed of Proterozoic, Paleozoic, Upper Cretaceous and Tertiary rocks (**figure 4-1.1**). Evidence indicates that block faulting took place mainly in Late Tertiary (Miocene and Pliocene) time. Reactivation of pre-Laramide and Laramide faults may account for some of the offset.

General Geology

Precambrian granitic rocks of the Burro Mountains batholith were emplaced into older Precambrian metamorphosed sedimentary and igneous rocks of two series. Older metamorphic rocks (Bullard Peak series)(see appendix B), consisting of roof pendants and xenoliths in the batholith, were formed by amphibolite facies regional metamorphism of sedimentary and igneous protoliths. Younger metamorphic rocks (Ash Creek series) were formed by regional greenschist metamorphism and by contact metamorphism of sedimentary rocks. Within the Burro Mountains batholith, several intrusive episodes are apparent (anorthosite, diabase, and granite), but the most abundant rocks are granitic in composition, and include pegmatite and aplite. Younger (possibly Cambrian) syenites are dikes in the Proterozoic granite (McLemore and McKee, 1988).

Volcanic rocks and Cretaceous sedimentary rocks overlie the basement rocks; Paleozoic and Lower Mesozoic rocks have been stripped from the Burro Mountains uplift. Precambrian Burro Mountains batholith is intruded by the Laramide quartz monzonite Tyrone stock and by many rhyolitic plugs and dikes. The post-Laramide Schoolhouse Mountain caldera is described from the northern part of the range. Quaternary and Tertiary Gila Conglomerate and Holocene unconsolidated sediments are present in stream valleys.

The Big Burro Mountains block is faulted and fractured; northwest, northeast, and east-northeast fractures and shears are apparent. Northwest-directed features, the oldest in the series, have apparently been reactivated at various times; northeast and east-northeast zones are probably of differing ages. The range is bounded on the northeast by the steeply southwest-dipping Mangas Fault (**figure 4-1.1**). The Little Burro Mountains lie on the west side of the fault, and are composed of Precambrian granite and Cretaceous sedimentary rocks that are intruded by Tertiary stocks and overlain by volcanic flows. Big Burro Mountains lie east of the Mangas Fault, and are composed mainly of the Precambrian Burro Mountains batholith (Burro Mountains granite) intruded by Precambrian diabase dikes, dikes and plugs of rhyolite and other rock types and ages, and Tyrone stock (see McLemore and others, this volume). On the southwest side of the Big Burro Mountains fault block, a northwest-trending graben called the

Gold Hill block contains a thick series of undifferentiated Tertiary volcanic rocks (Knight's Peak series), and thick (763 m) deposits of Gila Conglomerate (see also Gold Hills, this section). The block, bounded on the northeast by the Taylor (Knight Peak) fault and on the southwest by the Malone fault. The block is underlain by Precambrian rocks similar to those occurring in the Big Burro Mountains block, but it lacks the intrusive plugs and stocks present in the Big Burro Mountains block. Regional emplacement of intrusives and occurrences of associated mineralization are localized along faults and fractures.

Units of the Schoolhouse Mountain caldera were described by Wargo (1959) in the Big Burro Mountains, but the caldera was not outlined or discussed until later (Wahl, 1980). The caldera is interpreted to be asymmetrical, as much as 1.5 km deep, and filled with the Schoolhouse Mountain Formation (Wahl, 1980). Ring-fracture faults occur on the southern and southwestern side of the caldera. Volcanic activity took place about 30 m.y. ago (Oligocene). Volcanic rocks are commonly hydrothermally altered to an aggregate of iron oxides and clay minerals. Quartz is locally abundant.

Mineral Resources

The Burro Mountains mining district includes the Big and Little Burro Mountains. The Burro Mountains mining district encompasses deposits of the Tyrone mine that contains Laramide base-metal, fluorite-gold, and associated uranium deposits. Fluorite occurs as vein filling in Precambrian rocks, and fluorspar mines are located along the major fault traces (Gillerman, 1952). The Black Hawk, Telegraph, and Cora Miller mining districts are located in the northern Burro Mountains; Bound Ranch (Langford Hills) mining district is in the southern Burro Mountains. Malone mining district lies in the southwestern part of the Burro Mountains. White Signal district encompasses the southeastern part of the Burro Mountains and nearby isolated hills and plains to the south and southeast.

Three main episodes of mineralization took place in the Big Burro Mountains. In Precambrian time, contact metamorphism and pegmatite formation occurred during the intrusion of the Burro Mountains batholith. Later, in Late Cretaceous-early Tertiary time, the Tyrone stock was emplaced and resulted in base-metal mineralization. Later volcanism resulted in the predominance of fluorite-gold mineralization. Tyrone ore body, the main ore deposit in the Burro Mountains, has produced large quantities of copper. Structural features, such as the faults and fractures previously mentioned, typically concentrate the ore.

References

(* reference used in writing above summary)

Cook, S.S., 1993, Supergene copper mineralization at the Tyrone mine, Grant County, New Mexico [abs.]: Society for Mining, Metallurgy and Exploration, Inc., 1993 Annual Meeting and Exhibit, Program with Abstracts, p. 139.

*Drewes, H., 1989c, Summary, *in* Drewes, Harald, and Dyer, Russ, 1989, Tectonics of the eastern part of the Cordilleran Orogenic Belt, Chihuahua, New Mexico, and Arizona; Field Trip Guidebook T121, 28th International Geological Congress: American Geophysical Union, Washington, D.C., p. 1-3.

DuHamel, J.E., Cook, S.S., and Kolessar, J., 1995, Geology of the Tyrone porphyry copper deposit, New Mexico; *in* Pierce, F.W. and Bolm, J.G., eds., Porphyry copper deposits of the American Cordillera: Arizona Geological Society Digest 20, p. 464-472.

*Elston, W.E., 1960, Reconnaissance geologic map of Virden 30' quadrangle: New Mexico Bureau of Mines and Mineral Resources Geologic Map 15, scale 1:126,720.

*Elston, W.E., 1958, Burro uplift, northwestern limit of sedimentary basin of southwestern New Mexico and southeastern Arizona: American Association of Petroleum Geologists Bulletin, v. 42, no. 10, p. 2513-2517.

Finnell, T.L., 1987, Geologic map of the Cliff quadrangle, Grant County, New Mexico: U.S. Geological Survey Miscellaneous Investigations Series Map I-1768.

Gerwe, J.E., 1986, Ag-Ni-Co-As-U mineralization in the Black Hawk Mining District, Grant County, New Mexico: Socorro, New Mexico Institute of Mining and Technology, unpublished Master's thesis, 85 p.

Gerwe, J.E., and Norman, D.I., 1985, Ag-Ni-Co-U mineralization in the Black Hawk mining district, Grant county, New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 199, p. 52.

*Gillerman, Elliot, 1952, Fluorspar deposits of the Burro Mountains and vicinity: U.S. Geological Survey Bulletin 973-F, p. 261-289.

Gillerman, E., 1953, White Signal uranium deposits; in Kottlowski, F. E., ed., Southwestern New Mexico: New Mexico Geological Society, Guidebook 4, pp. 133–137.

Gillerman, Elliot, 1964, Mineral deposits of western Grant County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 83, 213 p.

Gillerman, Elliot, 1967, Structural framework and character of mineralization, Burro Mountains, New Mexico: Economic Geology, v. 62, p. 370-375.

Gillerman, E., 1968, Uranium mineralization in the Burro Mountains, New Mexico: Economic

Geology, v. 63, no. 3, p. 239-246.

Gillerman, Elliot, 1970, Mineral deposits and structural pattern of the Big Burro Mountains, New Mexico, *in* Woodward, L.A., ed., Guidebook of the Tyrone-Big Hatchet Mountains-Florida Mountains Region: New Mexico Geological Society, 21st Annual Field Conference, p. 115-121.

Gillerman, Elliot, and Whitebread, D.H., 1956, Uranium-bearing nickel-cobalt-native silver deposits, Black Hawk District, Grant County, New Mexico: U.S. Geological Survey Bulletin 1009-K, 283-311.

Hedlund, D.C., 1978c, Geologic map of the Burro Peak quadrangle, Grant County, New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map MF-1040; scale 1:24,000.

Hedlund, D. C., 1978g, Geologic map of the Tyrone quadrangle, Grant County, New Mexico: U. S. Geological Survey, Miscellaneous Field Studies Map MF-1037, scale 1:24,000.

Hedlund, D. C., 1978j, Geologic map of the Wind Mountain quadrangle, Grant County, New Mexico: U. S. Geological Survey, Miscellaneous Field Studies Map MF-1031, scale 1:24,000.

Hedlund, D.C., 1985a, Geology, mines, and prospects of the Tyrone stock and vicinity, Grant County, New Mexico: U.S. Geological Survey Open-File Report OF 85-232, 31 p.

Hedlund, D.C., Stacey, J.S., and Marvin, R.F., 1981, Precambrian dated sequence, Burro Mountains, New Mexico: U.S. Geological Survey Professional Paper 1275, p. 70-71.

Hewitt, C.H., 1957, Geology of the Burro Mountains-Redrock area, New Mexico: Ann Arbor, University of Michigan, unpublished Ph.D. dissertation.

*Hewitt, C.H., 1959, Geology and mineral deposits of the northern Big Burro Mountains-Redrock area, Grant County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 60, 151 p.

Kolessar, J., 1970, Geology and copper deposits of the Tyrone district, *in* Woodward, L.A., ed., Guidebook of the Tyrone-Big Hatchet Mountains-Florida Mountains Region: New Mexico Geological Society, 21st Annual Field Conference, p. 127-132.

Kolessar, J., 1982, The Tyrone copper deposits, Grant county, New Mexico, *in* Titley, S.R., ed., Advances in geology of the porphyry copper deposits: University of Arizona Press, p. 327-333.

Lindgren, W., Graton, L.C., and Gordon, C.H., 1910, The ore deposits of New Mexico: U.S. Geological Survey Professional Paper 68, 361 p.

*Mack, F.H., and Clemons, R.E., 1988, Structural and stratigraphic evidence for the Laramide (early Tertiary) Burro Uplift in southwestern New Mexico, *in* Mack, F.H., Lawton, T.F.,

and Lucas, S.G., eds., Cretaceous and Laramide tectonic evolution of southwestern New Mexico: New Mexico Geological Society Guidebook, 39th Field Conference, p. 58-66.

McDowell, F.W., 1971, K-Ar ages of igneous rocks from the western United States: Isochron/West, no. 2, p. 1-16.

*McLemore, V.T., and McKee, C., 1988a, A preliminary geochemical study of the Redrock anorthosite and granite, Burro Mountains, southwestern New Mexico, *in* Mack, F.H., Lawton, T.F., and Lucas, S.G., eds., Cretaceous and Laramide tectonic evolution of southwestern New Mexico: New Mexico Geological Society, 39th Annual Field Conference, Deming, N. Mex., p. 82-88.

*McLemore, V.T., and McKee, C., 1988b, Geochemistry of the Burro Mountains syenites and adjacent Proterozoic granite and gneiss and the relationship to a Cambrian-Ordovician alkalic magmatic event in New Mexico and southern Colorado, *in* Mack, F.H., Lawton, T.F., and Lucas, S.G., eds., Cretaceous and Laramide tectonic evolution of southwestern New Mexico: New Mexico Geological Society, 39th Annual Field Conference, Deming, N. Mex., p. 89-98.

O'Neill, A.J., and Thiede, D.S., 1982, Silver City quadrangle, New Mexico and Arizona: Bendix Field Engineering Corporation, Grand Junction Operation PGJ/F-131(82), 87 p.

Paige, Sidney, 1922, Copper deposits of the Tyrone district, New Mexico: U.S. Geological Survey Professional Paper 122.

Richter, D.H., and Lawrence, V.A., 1983, Mineral deposit map of the Silver City $1^{o}x2^{o}$ quadrangle, New Mexico and Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map I-1310-B, 70 p., scale 1:250,000.

Somers, R.E., 1916, Geology of the Burro Mountain copper district, New Mexico: American Institute of Mining Engineers Transactions, v. 52, p. 604-656.

Von Bargen, D.J., 1979, The silver-antimony-mercury system and the mineralogy of the Black Hawk District, New Mexico: Lafayette, Ind., Purdue University, unpublished Ph. D. dissertation, 260 p.

Von Bargen, D.J., 1993, Minerals of the Black hawk district, New Mexico: Rocks and Minerals, v. 68, no. 2, p. 96-111, 132-133.

*Wahl, D.E., 1980, Mid-Tertiary volcanic geology in parts of Greenlee County, Arizona, Grant and Hidalgo Counties, New Mexico: Tempe, Arizona State University, unpublished Ph. D. dissertation, 144 p.

*Wargo, J.G., 1959, Geology of the Schoolhouse Mountain quadrangle, Grant County, New Mexico: Tucson, University of Arizona, unpublished Ph. D. dissertation, 187 p.

Zalinski,, E.R., 1907, Turquoise in the Burro Mountians, New Mexico: Economic Geology, v. 2, no. 5, p. 464-492.

GOLD HILL AREA

The Gold Hill area is located south of the Big Burro Mountains and northeast of Lordsburg (in discussions of the Big Burro Mountains, this range is referred to as the Gold Hills block). The range is separated from the Big Burro Mountains to the north by an alluvial valley.

General Geology

Gold Hill block is located on the southern edge of the Burro Uplift, and is a northwest–trending fault block composed mainly of granitic and metamorphic rocks of Precambrian age [part of the Burro Mountain batholith of Gillerman (1964)], although Laramide volcanic rocks and Upper Tertiary and Quaternary semiconsolidated to unconsolidated sediments are also present Beard and Brookins, 1988). Minor intrusions include various types of dikes, plugs, and pegmatite. (**figure 4-1.2**).

Precambrian rocks make up the majority of the range, and consist primarily of granite (granite, biotite granite, quartz monzonite, and diorite), amphibolite, gneiss, impure quartzite, small pods and xenoliths, and migmatites; minor intrusions include pegmatite, aplite dikes, quartz plugs, diabase dikes and plugs, basalt dikes, and felsic dikes (Beard and Brookins, 1988). Foliation in the Precambrian metamorphic sequences is northwest-trending. Dikes trend generally east-northeast, have nearly vertical dips; they strike parallel to the predominant east-northeast jointing direction (however, the joints have variable dip direction, and the dikes are typically vertical). Faults are difficult to recognize within these rock units, and stratigraphic succession was obliterated by metamorphism and intrusion.

Mineral Resources

Gold Hill mining district in Grant and Hidalgo Counties contains gold-bearing quartz veins of probable Laramide age, with minor fluorite, REE-enriched pegmatite, scheelite (tungsten), and base-metal deposits. Placer deposits are insignificant, but gold-bearing quartz veins that occur in contact with mafic and felsic rocks have economic importance.

References

(* reference used in writing above summary)

Beard, R.D., 1987, Geology and geochemistry of the central part of the Gold Hill mining district, Hidalgo and Grant Counties, New Mexico: Albuquerque, University of New Mexico, unpublished M.S. thesis.

Beard, R.D., and Brookins, D.G., 1986, Geology and geochemistry of the central part of the Gold Hill mining district, Hidalgo and Grant Counties, New Mexico [abs.]: New Mexico

Geology, v. 8, no. 3, p. 68.

*Beard, R.D., and Brookins, D.G., 1988, Geology and mineral deposits of the Gold Hills, Hidalgo and Grant Counties, New Mexico, *in* Mack, G.H., Lawton, T.F., and Lucas, S.G., eds., Cretaceous and Laramide tectonic evolution of southwestern New Mexico: New Mexico Geological Society, 39th Annual Field Conference, Guidebook, p. 203-210.

Gillerman, Elliot, 1964, Mineral deposits of western Grant County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 83, 213 p.

Hedlund, D. C., 1977a, Mineral resources of the Hillsboro and San Lorenzo quadrangles, New Mexico: U. S. Geological Survey, Miscellaneous Field Studies Map MF-900B, scale 1:48,000.

Hedlund, D.C., 1977b, Geologic map of the Hillsboro and San Lorenzo quadrangles, Sierra and Grant Counties, New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map 900-A, scale 1:48,000

Hedlund, D.C., 1978b, Geologic map of the C Bar Ranch quadrangle, Grant County, New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map MF-1039, scale 1:24,000.

Hedlund, D.C., 1978e, Geologic map of the Ninety-six Ranch quadrangle, New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map MF-1034, scale 1:24,000.

Hedlund, D.C., 1978f, Geologic map of the Gold Hill quadrangle, New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map MF-1035, scale 1:24,000.

Hedlund, D. C., 1978j, Geologic map of the Wind Mountain quadrangle, Grant County, New Mexico: U. S. Geological Survey, Miscellaneous Field Studies Map MF-1031, scale 1:24,000.

McLemore, V.T., North, R.M., and Leppert, Shawn, 1988, REE, niobium, and thorium districts and occurrences in New Mexico: New Mexico Bureau of Mines and Mineral Resources Open File Report 324, 27 p.

Richter, D.H., and Lawrence, V.A., 1983, Mineral deposit map of the Silver City 1^{o} x2^{o} quadrangle, New Mexico and Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map I-1310-B, 70 p., scale 1:250,000.

KNIGHT PEAK AREA (GRANT COUNTY)

The Knight Peak area is located near the continental divide,from Soldier's Farewell Hill to the Big Burro Mountains (**figure 1-1**). The area, located southwest of the Big Burro Mountains, is composed of the northwest–trending Knight Peak half-graben (Davis and others, 1988).

General Geology

The Knight peak half-graben contains northeast-tilted Precambrian through Tertiary rocks of the Burro uplift and post-volcanic conglomerates (Gila Conglomerate)(**figure 4-1.3**). Precambrian granite and diabase underlie outliers of Bliss Sandstone; the Bliss is conformably overlain by fossiliferous Late Cambrian to Early Ordovician El Paso Limestone (appendix B). Cretaceous rocks tentatively identified as Lobo Formation are unconformable on all older sequences, including Precambrian rocks. Tertiary volcanic and intrusive rocks unconformably overlie Cretaceous and older rocks and form the major part of the Knight Peak range. From base to top, these rocks include intrusive andesite, rhyolitic rocks, vitric rhyolitic breccia, andesitic flows, andesitic and rhyolitic tuffs, perlite, and agglomerate; Tertiary rocks are as much as 1,983 m thick. The poorly exposed contact between the Tertiary and Precambrian rocks has been variously mapped as a fault (Ballman, 1960) and as an unconformity with localized faulting (Hedlund, 1978). Gila Conglomerate that unconformably overlies the Tertiary units is highly variable in thickness, in part because of faulting. The Gila fanglomerates are very poorly sorted, and contain large boulders that are probably derived from the Big Burro Mountains. Younger Quaternary volcanic rocks occur as conelike masses, and are composed of rhyolite flows and dikes, intrusive bodies, dacite flows, and andesitic rocks. Quaternary sediments, mostly pediment gravels and fluvial deposits, are widespread. Fluvial deposits may be as thick as 12 m.

The Malone fault to the west and Taylor (Knight Peak) fault to the east are normal faults and the major northwest–trending faults that bound the Knight Peak graben. High-angle (vertical) northeast-trending faults intersect the northwest-trending faults. The range is dissected into as many as three fault-bounded blocks by faulting and tilting, and rocks as young as Gila Conglomerate are deformed by the tectonic activity along the faults—evidence that faulting and tilting took place as late as late Tertiary-early Quaternary time. Reactivation of older faults is suggested, however.

Mineral Resources

Perlite deposits are present in volcanic sequences of the area. Fluorite occurs as vein filling in Precambrian rocks, and fluorspar mines are located along the major fault traces. (Gillerman, 1952)

References

(* reference used in writing above summary)

*Ballman, D.L., 1960, Geology of the Knight Peak Area, Grant County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 70, 39 p.

Correa, B.P., 1980, Fluorine and lithophile element mineralization in the Black Range and Sierra

Cuchillo, New Mexico, *in* Burt, D.M., Sheridan, M.F., Bikun, J., Christiansen, E., Correa, B.P., Murphy, B., and Self, S., ed., Uranium mineralization in fluorine-enriched volcanic rocks--Final report: GJBX-225-80, p. 459-494.

Davis, Keith, 1986, An integrated geophysical study of the Knight Peak graben: Las Cruces, New Mexico State University, unpublished M.S. thesis, 56 p.

*Davis, K., Harder, S., Greensfelder, R.W., and Ni, J., 1988, An integrated geophysical study of the Knight Peak graben, *in*Mack, F.H., Lawton, T.F., and Lucas, S.G., eds., Cretaceous and Laramide tectonic evolution of southwestern New Mexico: New Mexico Geological Society, 39th Annual Field Conference, Deming, N. Mex., p. 76-81.

*Hedlund, D.C., 1978b, Geologic map of the C Bar Ranch quadrangle, Grant County, New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map MF-1039, scale 1:24,000.

*Hedlund, D.C., 1978c, Geologic map of the Burro Peak quadrangle, Grant County, New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map MF-1040, scale 1:24,000.

*Hedlund, D.C., 1978d, Geologic map of the Soldiers Farewell Hill quadrangle, New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map MF-1033, scale 1:24,000.

Hedlund, D.C., Stacey, J.S., and Marvin, R.F., 1981, Precambrian dated sequence, Burro Mountains, New Mexico: U. S. Geological Survey Professional Paper 1275, p. 70-71.

Morrison, R.B., 1965 [1966], Geologic map of the Duncan and Canador Peak quadrangles, Arizona and New Mexico: U.S. Geological Survey Miscellaneous Investigations Series Map I-0442, scale 1:48,000.

MOGOLLON MOUNTAINS

The Mogollon Mountains are the highest range in southwestern New Mexico, and extend from Catron and Sierra Counties into northern Grant County. Thus, most of the range lies north of the Mimbres Resource Area. Mogollon-Datil volcanic field and calderas within the field make up the principle structures of the Mogollon Mountains. The Mogollon Mountains are hypothesized to be underlain by Precambrian and Paleozoic sequences.

General Geology

Regionally, Tertiary volcanic rocks that are divisible into pre-caldera sequences, caldera-related sequences, and post-caldera sequences are present (Ratté and others, 1984). From base to top, these volcanic rocks include (1), andesite and latite flow breccias, flows, pyroclastic rocks, and intrusives that may be highly altered and bleached; (2), latite and rhyolite tuffs and flows; and (3), a rhyolite sequence that includes rhyolite tuffs and flows.

Pre-Caldera Rocks

Pre-caldera rocks consist mostly of andesitic to rhyolitic vent complexes, and possibly some andesitic lavas along the southwestern mountain front. The Rubio Peak Formation, which crops out in the southeastern part of the Mogollon volcanic field, probably is equivalent to the pre-caldera sequence (Elston, 1976). Evidence in the western and northwestern part of the Mogollon Mountains suggests that the pre-caldera rocks were erupted as early as 37 m.y. ago from vents in that part of the range (Ratté and others, 1969; Ratté, 1980).

Caldera-Related Rocks

Bursum caldera

Bursum caldera, centered on the crest Mogollon Mountains, is a resurgent caldera. This type of caldera is commonly associated with ore deposits, and has the highest potential for containing the proper ore-forming hydrothermal systems of any caldera type (Smith and Bailey, 1969).

Bloodgood Canyon Tuff, a high-silica rhyolite, was erupted from incipient ring fractures of the Bursum caldera, causing its initial collapse. The Bloodgood Canyon Tuff is followed by the Apache Spring Tuff (basal rhyolite grading upward to dacite), which fills, and is restricted to, Bursum caldera (as much as 1,204 km^2 in extent). The Apache Spring Tuff, one of the most voluminous units of the Mogollon Mountains, overlies the Bloodgood Canyon Tuff,, but the Apache Spring and Bloodgood Canyon Tuffs have indistinguishable radiometric ages of about 29 m.y. The Apache Spring Tuff is locally overlain by post-collapse andesitic lava flows, ring-fracture rhyolite flows, and pyroclastic rocks that are probably moat deposits laid down after resurgent doming. A final, pre-resurgent dome deposit is the rhyolite of Sacaton Mountain (dacite to rhyolite, but mostly rhyolite) that occurs on the south side of the resurgent dome. The unit is probably derived from the Apache Spring tuff after the volatile components of the magma had dissipated (Rhodes, 1976; Ratté and others, 1984).

Eruptions of caldera-related tuffs was followed by voluminous rhyolitic volcanism from a ring-fracture system within the Bursum caldera, and by resurgent domal uplift in the central part of the caldera. Lava flows from this episode partially obscure the walls of the caldera (Ratté and others, 1984), but a portion is well exposed in the Mogollon mining district. The Bursum caldera is generally outlined by ring-fracture rhyolites and related rocks (domes, plugs, dikes) that are the youngest rocks in the volcanic series. These post-caldera rhyolitic rocks occur mainly near the caldera margin, but scattered remnants are also found along the crest of the range. They probably once covered the resurgent dome, but have been eroded away (Ratté and others, 1984). Ring-fractures, from which the post-caldera lavas flowed, have been buried by subsequent flows

and volcaniclastic deposits, including landslide and fluvial debris. All of the deposits have been faulted during later Basin-and-Range extensional tectonism.

Gila Cliff Dwellings caldera

The Bloodgood Canyon Tuff, although it fills the Gila Cliff Dwellings caldera, may not have originated in it. However, evidence for Gila Cliff Dwellings caldera is in the thickness and distribution of the Bloodgood Canyon Tuff and exposed post-caldera faults on the east side of the edifice (Ratté and others, 1984). The Bloodgood Canyon Tuff, a single cooling unit, is not exposed in its entirety (the base is covered), but it is at least 305 m thick, and may be as much as 610 m thick. Evidence, such as the compositional purity of the tuff and its large volume and distribution, make questionable its source in the Gila Cliff Dwellings caldera. Rather, two other tuff units, the Davis Canyon Tuff and Shelley Peak Tuff (both about 30 m.y. old), have more limited distributions, suggesting that their sources are probably in the Gila Cliff Dwellings caldera (Ratté and others, 1984). Field relations suggest strongly that the Davis Canyon and Shelley Peak tuffs are coextensive and gradational, and although they differ in composition, that they may have originated from closely related sources.

Configuration of the Gila Cliff Dwellings caldera is not known, owing to burial of the caldera by lavas and volcaniclastic strata that blanket the area on the north, south, and east. The caldera diameter is estimated to be about 19 km. Post-caldera-collapse features have not been identified with any degree of certainty.

Mogollon caldera

Mogollon caldera, centered near the town of Glenwood, Catron County, is the oldest ash-flow subsidence feature of the Mogollon Mountains (about 34 m.y. old). Because it is mostly buried under younger rocks, its size, shape, and location are equivocal. Cooney Tuff, probably an intracaldera ash-flow unit, provides the primary evidence for the buried Mogollon caldera (Ratté and Finnell, 1978; Ratté, 1981). Cooney Tuff is exposed along the southern edge of the Mogollon range and is at least 702 m thick (base not exposed) in the Mogollon mining district. Cooney Tuff is divided into the lower Whitewater Creek Member (high-silica rhyolite that represents a single cooling or eruptive event) and the upper Cooney Canyon Member (rhyolitic to dacitic rocks that represent numerous eruptive events separated by andesitic sandstone beds). Whitewater Creek Member probably represents the initial rapid and voluminous eruption from the Mogollon caldera, and the Cooney Canyon Member probably represents waning eruptive events following subsidence of the caldera.

Post-Caldera Rocks

Post-caldera rocks are composed of andesitic volcanic units that were erupted as early as 25 m.y. ago. These mostly basaltic or mafic rocks overlie deposits of the resurgent Bursum caldera and the deposits associated with rhyolitic or silicic ring-fracture systems of the caldera. Mafic volcanism waned gradually. A series of eruptive units with a higher silicic component were interbedded with the mafic units, which indicated the beginning of Basin-and-Range extension in the Rio Grande rift.

Quaternary volcanic and sedimentary rocks overlie the Tertiary units. Quaternary sequences are basalt and basaltic andesite flows and flow breccias, rhyolite flows, volcanic domes, plugs, tuffs, and ash. Basalts contain amygdaloid-filling zeolites, calcite, clay, and silica minerals. The basalt is overlain unconformably by Gila Conglomerate, comprised of sandstone, conglomerate, thin beds of rhyolite tuff, localized deposits of pediment gravel, alluvium, alluvial fan deposits, and lacustrine clay, silt, and diatomite.

Mineral Resources

Major copper porphyry, silver-gold-copper, tellurium, lead-zinc-copper, and fluorite deposits and potential molybdenum and aluminum deposits exist in the range. Small known resources of lead-zinc-copper-cadmium and gold-bearing quartz veins are also present. Meerschaum clay, other clays, and aluminum salts are locally present. Wilcox (Seventy-four) mining district is located in northwest Grant County and extends northwestward into Catron County.

References

(* reference used in writing above summary)

Bikerman, Michael, 1972, New K-Ar ages on volcanic rocks from Catron and Grant Counties, New Mexico: Isochron/West, no. 3, p. 9-12.

Bornhorst, T.J., 1980, Major- and trace-element geochemistry and mineralogy of upper Eocene to Quaternary volcanic rocks of the Mogollon-Datil volcanic field, southwestern New Mexico: Albuquerque, University of New Mexico, unpublished Ph. D. dissertation, 1108 p.

Bornhorst, T.J., 1986, Granophile elements in mid-Cenozoic calc-alkalic rhyolitic volcanic rocks, Mogollon-Datil volcanic field, southwestern New Mexico, *in* Taylor, R.P. and Strong, D.F., eds., Recent advances in the geology of granite-related mineral deposits: The Canadian Institute of Mining and Metallurgy, Special Volume 39, p. 331-341.

Bornhorst, T.J., 1988, Character of mid-Cenozoic andesites, basaltic andesites, and related volcanic rocks, Mogollon-Datil volcanic field, southwestern New Mexico, *in* Drexler, J.W., and Larson, E.E., Cenozoic volcanism in the Southern Rocky Mountains

updated--A tribute to Rudy C. Epis--Part 2: Colorado School of Mines Quarterly, v. 83, p. 1-13.

Bornhorst, T. J., Jones, D. P., Elston, W. E., Damon, P. E., and Shafiqullah, M., 1982, New radiometric ages on volcanic rocks from the Mogollon-Datil field, southwestern New Mexico: Isochron/West, no 35, p. 13-14.

Briggs, J.P., 1981, Mines and prospects map of the Hells Hole further planning area (RARE II), Greenlee County, Arizona, and Grant County, New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map MF-1344-C, scale 1:62,500.

Briggs, J.P., 1982, Mineral investigation of the Hells Hole Roadless area, Greenlee County, Arizona and Grant County, New Mexico: U.S. Bureau of Mines Open-file Report MLA 137-82, 22 p.

Brooks, W.E., and Ratté, J.C., 1985, Geologic map of Bear Mountain quadrangle, Grant County, New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map MF-1782, scale 1:24,000.

Chapin, C.E., Elston, W.E., and James, H.L., eds., 1978, Field guide to selected cauldrons and mining districts of the Datil-Mogollon volcanic field, New Mexico: 149 p.

Coney, P.J., 1976, Structure, volcanic stratigraphy, and gravity across the Mogollon Plateau, New Mexico *in* Elston, W.E., and Northrop, S.A., eds., Cenozoic volcanism in southwestern New Mexico: p. 29-41.

Diehl, J.F., McClannahan, K.M., and Bornhorst, T.J., 1988, Paleomagnetic results from the Mogollon-Datil volcanic field, southwestern New Mexico, and a refined mid-Tertiary reference pole for North America: Journal of Geophysical Research, v. 93, no. 5, p. 4869-4879.

Eaton, G.P., Peterson, D.L., and Webring, M.W., 1977, Bouguer gravity map of the Mogollon-Santa Rita-Tyrone region, southwestern New Mexico: U.S. Geological Survey Open-File Report 77-0650.

Elston, W.E., 1968, Terminology and distribution of ash flows of the Mogollon-Silver City-Lordsburg region, New Mexico: Arizona Geological Society Guidebook III to southern Arizona, p. 231-240.

Elston, W.E., 1976, Glossary of stratigraphic terms of the Mogollon-Datil volcanic province, New Mexico *in* Elston, W.E., and Northrop, S.A., eds., Cenozoic volcanism in southwestern New Mexico: p. 131-145.

Elston, W.E., 1978, Mid-Tertiary cauldrons and their relationship to mineral resources, southwestern New Mexico --A brief review, *in* Chapin, C.E., Elston, W.E., and James,

H.L., eds., Field guide to selected cauldrons and mining districts of the Datil-Mogollon volcanic field, New Mexico: New Mexico Geological Society Special Publication no. 7, p. 107-113.

Elston, W.E., 1984a, Mid-Tertiary ash flow tuff cauldrons, southwestern New Mexico: Journal of Geophysical Research, v. 89, no. 10, p. 8733-8750.

Elston, W.E., 1994, Siliceous volcanic centers as guides to mineral exploration --review and summary: Economic Geology, v. 89, no. 8, p. 1662-1686.

Elston, W.E., Coney, P.J., and Rhodes, R.C., 1970, Progress report on the Mogollon Plateau Volcanic Province, Southwestern New Mexico: No. 2, *in* Woodward, L.A., ed., Guidebook of the Tyrone-Big Hatchet Mountains-Florida Mountains Region: New Mexico Geological Society, 21st Annual Field Conference, p. 75-86.

Elston, W.E., Damon, P.E., Coney, P.J., Rhodes, R.C., Smith, E.I., and Bikerman, M., 1973, Tertiary volcanic rocks, Mogollon-Datil province, New Mexico, and surrounding region: K-Ar dates, patterns of eruption, and periods of mineralization: Geological Society of America Bulletin, v. 84, p. 2259-2274.

Elston, W.E., Rhodes, R.C., Coney, P.J., and Deal, E.G., 1976a, Progress report on the Mogollon Plateau volcanic field southwestern New Mexico, no. 3--Surface expression of a pluton, *in* Elston, W.E., and Northrop, S.A., eds., Cenozoic volcanism in southwestern New Mexico: New Mexico Geological Society Special Publication No. 5, p. 3-28.

Ferguson, H.G., 1927, Geology and ore deposits of the Mogollon mining district, New Mexico: U.S. Geological Survey Bulletin 787, 100 p.

Finnell, T. L., 1976, Geologic map of the Twin Sisters quadrangle, Grant County, New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map MF-779.

Finnell, T. L.,1987, Geologic map of the Cliff quadrangle, Grant County, New Mexico: U.S. Geological Survey Miscellaneous Investigations Series Map I-1768.

Futa, K., and Ratté, J.C., 1989, Petrogenetic implications of Rb-Sr and Sm-Nd isotopes related to post-caldera volcanism in the western Mogollon-Datil volcanic field, New Mexico, *in* Barker, C.E., and Coury, A.B., eds., Abstracts of the U.S. Geological Survey, central region, 1989 poster review; collected abstracts of selected poster papers presented at scientific meetings: U.S. Geological Survey Open-File Report 89-0644, p. 17.

Gillerman, Elliot, 1964, Mineral deposits of western Grant County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 83, 213 p.

Marvin, R.F., Naeser, C.W., Bikerman, M., Mehnert, H.H., and Ratté, J.C., 1987, Isotopic ages of post-Paleocene igneous rocks within and bordering the Clifton 1°x2° quadrangle,

Arizona-New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 118, 63 p.

*McIntosh, W.C., 1991, Evaluation of paleomagnetism as a correlation criterion for Mogollon-Datil ignimbrites, southwestern New Mexico: Journal of Geophysical Research, v. 96, no. 8, p. 13,459-13,483.

*McIntosh, W.C., Chapin, C.E., Ratté, J.C., and Sutter, J.F., 1992, Time-stratigraphic framework for the Eocene-Oligocene Mogollon-Datil volcanic field, southwest New Mexico: Geological Society of America Bulletin, v. 104, p. 851-871.

Ratté, J.C., 1982 (1983), Reserve graben, southwestern New Mexico and eastern Arizona, *in* Geological Survey Research 1982: U.S. Geological Survey Professional Paper, p. 61.

*Ratté, J.C., and Briggs, J.P., 1984, Hells Hole Roadless Area, Arizona and New Mexico, *in* Marsh, S.P., Kropschot, S.J., and Dickinson, R.G., eds., Wilderness mineral potential; assessment of mineral resource potential in U.S. Forest Service lands studied 1964-1984: U.S. Geological Survey Professional Paper 1300, p. 73-75.

Ratté, J.C., and Gaskill, D.L., 1975-1976, Reconnaissance geologic map of the Gila Primitive Area and Gila Wilderness study area, southwestern New Mexico: U.S. Geological Survey Miscellaneous Investigations Series Map I-0886.

*Ratté, J.C., and Lane, M.E., 1984, Lower San Francisco Wilderness Study Area and contiguous roadless areas, Arizona and New Mexico, *in* Marsh, S.P., Kropschot, S.J., and Dickinson, R.G., eds., Wilderness mineral potential; assessment of mineral-resource potential in U.S. Forest Service lands studied 1964-1984: U.S. Geological Survey, Professional Paper 1300, p. 79-82.

Ratté, J.C., Gaskill, D.L., Eaton, G.P., Peterson, D.L., Stotelmeyer, R.B., and Meeves, H.C., 1979, Mineral resources of the Gila Primitive Area and Gila Wilderness, New Mexico: U.S. Geological Survey Bulletin 1451, 229 p.

Ratté, J.C., Marvin, R.F., and Naeser, C.W., 1984, Calderas and ash flow tuffs of the Mogollon Mountains, southwestern New Mexico: Journal of Geophysical Research, v. 89, no. 10, p. 8713-8732.

*Ratté, J.C., and Stotelmeyer, R.B., 1984, Gila Wilderness, New Mexico, *in* Marsh, S.P., Kropschot, S.J., and Dickinson, R.G., eds., Wilderness mineral potential; assessment of mineral resource potential in U.S. Forest Service lands studied 1964-1984: U.S. Geological Survey Professional Paper 1300, p. 811-813.

*Ratté, J.C., Marvin, R.F., and Naeser, C.W., 1984, Calderas and ash flow tuffs of the Mogollon Mountains, southwestern New Mexico: Journal of Geophysical Research, v.

89, no. 10, p. 8713-8732.

Rhodes, R.C., 1970, Volcanic rocks associated with the western part of the Mogollon Plateau volcano-tectonic complex, southwestern New Mexico: Albuquerque, University of New Mexico, unpublished Ph. D. dissertation, 145 p.

Rhodes, R.C., 1976a, Petrologic framework of the Mogollon Plateau volcanic ring complex, New Mexico--surface expression of a major batholith, *in* Elston, W.E., and Northrop, S.A., eds., Cenozoic volcanism in southwestern New Mexico: New Mexico Geological Society, Special Publication 5, p. 103-112.

*Rhodes, R.C., 1976b, Volcanic geology of the Mogollon Range and adjacent areas, Catron and Grant Counties, New Mexico, *in* Elston, W.E., and Northrop, S.A., eds., Cenozoic volcanism in southwestern New Mexico: New Mexico Geological Society, Special Publication 5, p. 43-50.

Rothrock, H.E., Johnson, C.H., and Hahn, A.D., 1946, Fluorspar resources of New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 21, 245 p.

Smith, E.I., and Rhodes, R.C., 1971, The Mule Creek caldera, a recently discovered felsic volcanic center in southwestern New Mexico [abs.]: Geological Society of America Abstracts, v. 3, no. 2, p. 196.

Trauger, F.D., 1965, Geologic structure pattern of Grant County, New Mexico, *in* Fitzsimmons, J.P., and Lochman-Balk, Christina, eds., Guidebook of southwestern New Mexico II: New Mexico Geological Society, 16th Field Conference, p. 184-187.

Weber, R.H., and Bassett, W.A., 1963, K-Ar ages of Tertiary volcanic and intrusive rocks in Socorro, Catron, and Grant Counties, New Mexico, *in* Kuellmer, F.J., ed., Socorro Region: New Mexico Geological Society Guidebook, 14th Annual Field Conference, p. 220-223.

*Weber, R.H., and Willard, M.E., 1959, Reconnaissance geologic map of Mogollon 30' quadrangle: New Mexico Bureau of Mines and Mineral Resources Geologic Map 10, scale 1:126,720.

*Willard, Max, Weber, Robert, and Kuellmer, Frederick, 1961, Reconnaissance geologic map of Alum Mountain 30' quadrangle: New Mexico Bureau of Mines and Mineral Resources Geologic Map 13, scale 1:126,720.

Williams, F.E., 1966, Fluorspar deposits of New Mexico: U.S. Bureau of Mines Information Circular 8307, 143 p.

MIMBRES MOUNTAINS

(see also Black Range)

Mimbres Mountains are located in eastern Grant County, between the Black Range on the north and the Cookes Range on the south.

General Geology

Mimbres Mountains are composed of faulted, anticlinal Paleozoic limestone, sandstone, and shale, which are exposed mainly east of the study area in the vicinity of Kingston. These units are overlain by a series of north-trending Tertiary rhyolitic dikes, sills, porphyries, volcanic tuffs, flows, and shallow intrusives, and lenticular alluvial sediments containing fossil plants. An overlying upper volcanic group includes andesite and latite, rhyolite, basalt in scoriaceous to massive flows, and minor tuffs. Santa Fe Group and Mimbres Conglomerate are mainly unconsolidated alluvial sediments interbedded with basalt flows. Quaternary alluvium, talus, and terrace gravels are widespread. Emory caldera crops out in northern part of range.

Mineral Resources

Carpenter (Swartz) mining district is on the western slope of the Mimbres Mountains.

References

(* reference used in writing above summary)

Ericksen, G.E., Wedow, Helmuth, Jr., and Eaton, G.P., U.S. Geological Survey *and by* Leland, G.R., U.S. Bureau of Mines, 1970, Mineral resources of the Black Range Primitive Area, Grant, Sierra, and Catron Counties, New Mexico: U.S. Geological Survey Bulletin 1319-E, 162 p., 2 plates (aeromagnetic and geologic map; geochemical sampling map), scale 1;63,360.

Fitzsimmons, J.P., and Lochman-Balk, Christina, eds., 1965, Guidebook of southwestern New Mexico II: New Mexico Geological Society, Sixteenth Field Conference, 244 p.

Hedlund, D. C., 1977a, Mineral resources of the Hillsboro and San Lorenzo quadrangles, New Mexico: U. S. Geological Survey, Miscellaneous Field Studies Map MF-900B, scale 1:48,000.

Hedlund, D.C., 1977b, Geologic map of the Hillsboro and San Lorenzo quadrangles, Sierra and Grant Counties, New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map 900-A, scale 1:48,000

Hedlund, D.C., 1985b, Economic geology of some selected mines in the Hillsboro and San Lorenzo quadrangles, Grant and Sierra Counties, New Mexico: U.S. Geological Survey Open-File Report 85-456, 76 p.

Hill, R. S., 1946, Exploration of Grey Eagle, Grandview, and Royal John claims Grant and

Sierra Counties, New Mexico: U. S. Bureau of Mines, Report of Investigations 3904, 31 p.

*Kuellmer, F.J., 1956, Geologic map of Hillsboro Peak 30' quadrangle: New Mexico Bureau of Mines and Mineral Resources Geologic Map 1, scale 1:126,720.

Soulé, J.H., 1950, Investigation of the Royal John lead-zinc deposits, Grant County, New Mexico: U.S. Bureau of Mines, Report of Investigations 4748, 8 p.

Weissenborn, 1948, A new occurrence of helvite: American Mineralogist, v. 33, nos. 9-10, p.648-649.

PINOS ALTOS RANGE/ SILVER CITY RANGE, MOGOLLON MOUNTAINS

General Geology

Piños Altos Range and Silver City Range form the eastern border of a faulted monoclinal synclinorium, or horst, that extends to the northeast from the Big Burro Mountains. The synclinorium is made up of northeast-dipping, northwest-trending, Paleozoic and Cretaceous sedimentary rocks that rest on Precambrian granite and metamorphic rocks (**figure 4-1.4**). The sequence has been faulted both by northwest–trending faults (the Silver City and Mimbres Faults) and northeast– trending faults (including the Barringer Fault). The horst northwest of Santa Rita is deformed into the northeast– trending Fort Bayard Arch. Tertiary mafic porphyry dikes, andesitic, dacitic, rhyolitic, and latitic funnel-shaped stocks, breccias, and tuff deposits intrude and bury the older deposits. A complete stratigraphic sequence is exposed in the monocline, although the sequence has been repeatedly faulted, causing thickening and thinning of the units.

Precambrian and Paleozoic rocks are exposed where they are in contact with the Hanover–Fierro pluton and along the northwest-trending Mimbres fault. Paleozoic rocks, about 950 m thick, include the Bliss Sandstone, El Paso Formation, Montoya Group, Fusselman Dolomite, Percha Shale, Lake Valley Limestone, Oswaldo and Syrena Formations (Magdalena Group), Abo Formation, Beartooth Quartzite, and Colorado Formation. Paleozoic and Mesozoic sediments are folded, faulted, and intruded by numerous Tertiary dikes, sills, and plugs (Appendix B).

Cretaceous and Tertiary volcanic rocks, including Rubio Peak Formation, Sugarlump Tuff, and the Kneeling Nun Tuff, unconformably overlie the Paleozoic rocks. Intrusion of intermediate-composition stocks predated an extensive period of erosion and deposition of volcaniclastic rocks. The latest eruptions occurred during Oligocene time. Uplifts and breccia pipes that are related to the intrusive events have been described from the Santa Rita area. Hanover Hole, a possible subsidence caldera or volcanic vent, is a post-ore feature located south of the Hanover-Fierro pluton. Breccia pipes are located near the edge of Hanover Hole.

Folds and faults are typically related to Laramide intrusive events, when as much as 915 m of extrusive and intrusive rocks were deposited and (or) injected. The Mimbres fault bounds the Santa Rita horst on the northeast side; it is a reactivated Laramide fault (**figure 4-1.4**). The Mimbres fault trends northwest and dips about 70˚ NE; the northeast side is downdropped. Northeast– and east-northeast–trending faults occur mostly along the margin of the horst; the major fault within this trend is the Barringer Fault. These faults predate the Hanover– Fierro pluton (evidenced by stoping along the fault), and are probably related to intrusion of sills and domal uplift. Although the faults predate mineralization, they helped to localize it.

Later structural development during Basin-and-Range deformation resulted in faults that displace Tertiary to lower Quaternary basin fill deposits. Movement on the Mimbres Fault is evidenced by offset Pleistocene gravel.

Twin Sisters caldera

The Twin Sisters caldera (Piños Altos range; McIntosh and others, 1991), less than 40 km across, is filled with Tadpole Ridge Quartz Latite, a mineralogically distinct low-silica-rhyolite tuff. The southern caldera margin is located north of Piños Altos and the northern margin is buried. The caldera is designated by the thickness variation, lithology, and basal unconformity of Tadpole Ridge Quartz Latite.

City of Rocks and Giant of the Mimbres State Parks

City of Rocks State Park and Giant of the Mimbres are located on the southern tip of the Piños Altos Range. Sugarlump Tuff rhyolite is weathered into unusual 15-m-high pinnacles and boulders by etching processes developed in the subsurface along weathering fronts and along fractures in the ignimbrite sheet (Mueller and Twidale, 1988). The area of the park was occupied by early man, as evidenced by artifacts and pictographs, especially in the Faywood Hot Springs area.

Mineral Resources

Major porphyry copper deposits (Chino, Tyrone, Santa Rita, and Hanover-Fierro) have been mined from the region. The Bayard (Central) mining district is within the range.

High-calcium limestones may occur in Mississippian and Pennsylvanian rocks of the range (Kottlowski, 1962). Their extent is not known.

References

(* reference used in writing above summary)

Abramson, B.S., 1981, The mineralizing fluids responsible for skarn and ore formation at the Continental Mine, Fierro, New Mexico, in light of REE analyses and fluid inclusion studies: New Mexico Institute of Mining and Technology, unpublished Master's thesis,

143 p.

Ahmad, S.N., and Rose, A.W., 1980, Fluid inclusions in porphyry and skarn ore at Santa Rita, New Mexico: Economic Geology, v. 75, no. 2, p. 229-250.

Aldrich, M.J., Jr., 1974a, Structural development of the Hanover-Fierro pluton, southwestern New Mexico: Geological Society of America Bulletin, v. 85, no. 6, p. 963-968.

Aldrich, M.J., 1974b, Santa Rita-Hanover axis, New Mexico--Laramide structure with a late Tertiary Basin and Range trend [abs.]: Geological Society of America Abstracts with Programs, v. 6, no. 5, p. 421.

Aldrich, M.J., Jr., 1978, Subsurface extensions of the Santa Rita-Hanover axis; A major early Tertiary structure, New Mexico: Geology, v. 6, no. 6, p. 373-376.

Anderson, E.C., 1957, The metal resources of New Mexico and their economic features through 1954: New Mexico Bureau of Mines and Mineral Resources Bulletin 39, 183 p.

Anonymous, 1982, Boliden to explore Piños Altos Deposit: Mining Congress Journal, v. 68, no. 5, p. 7.

Backer, H.A., 1974, Geology of the Gila fluorspar district (Brock Canyon volcanic complex), Grant County, New Mexico (abs.): New Mexico Geological Society, Guidebook to the 25th Field Conference, p. 377.

Baker, Tanya G., 1993, Mobility of heavy metals in soils and tailings at the Hanover and Bullfrog tailings sites, Silver City, New Mexico: New Mexico Bureau of Mines and Mineral Resources Open-file report no. 393 (also Proceedings New Mexico Geological Society Spring Meeting, p. 28).

Ballmer, G.J., 1932, Native tellurium from northwest of Silver City, New Mexico: American Mineralogist, v. 17, no. 10, p. 491-492.

Belt, C.B., Jr., 1955, A petrographic and alteration study of the Hanover-Fierro intrusive, New Mexico: New York, Columbia University, unpublished Master's thesis.

*Blankenship, J.C., 1972, Stratigraphy and petrology of the El Paso Formation (Lower Ordovician) in the Silver City Range, New Mexico: University of Houston, unpublished Master's thesis.

Cady, F.H., 1938, Thermal metamorphism of sedimentary rocks of Hanover, New Mexico: Northwestern University, unpublished Master's thesis.

Carpenter, D.W., 1958, Hydrothermal alteration at Santa Rita, New Mexico: Pennsylvania State University, unpublished Master's thesis.

Chavez, W.X, Jr., 1991, Paragenesis of bismuth and associated silver-bearing phases, Piños Altos District, Grant County, New Mexico [abs.]: 11th Annual New Mexico Mineral

Symposium Proceedings, p. 5.
*Cunningham, J.E., 1974, Geologic map and sections of Silver City Quadrangle, New Mexico: New Mexico Bureau of Mines and Mineral Resources Geologic Map 30, scale 1:24,000.
Dale, V.B., and McKinney, W.A., 1959, Tungsten deposits of New Mexico: U.S. Bureau of Mines Report of Investigations 5517, 72 p.
Drewes, H.D., Houser, B.B., Hedlund, D.C., Richter, D.H., Thorman, C.H., and Finnell, T.L., 1985, Geologic map of the Silver City 1° x 2° quadrangle, New Mexico and Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map I-1310-C.
Eaton, G.P., Peterson, D.L., and Webring, M.W., 1977, Bouguer gravity map of the Mogollon-Santa Rita-Tyrone region, southwestern New Mexico: U.S. Geological Survey Open-File Report 77-0650.
*Elston, W.E., Weber, R.H., and Trauger, F.D., 1965, Road log from Silver City to junction of New Mexico Highways 61 and 90, *in* Fitzsimmons, J.P., and Lochman-Balk, Christina, eds., Guidebook of southwestern New Mexico II: New Mexico Geological Society, 16th Field Conference, p. 45-62.
Entwistle, L.P., 1944, Manganiferous iron-ore deposits near Silver City, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 19, 72 p.
Forrester, J.D., 1972, Skarn formation and sulfide mineralization at the Continental Mine, Fierro, New Mexico: Ithaca, N.Y., Cornell University, unpublished Ph. D. dissertation.
Gibson, W. A., and Trujillo, A. D., 1966, From Indian scrapings to 85-ton trucks--The development of Chino: Mining Engineering, v. 18, no. 1, p. 54-60.
Gillerman, Elliot, 1964, Mineral deposits of western Grant County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 83, 213 p.
Gillerman, E., and Whitebread, D.H., 1956, Uranium-bearing nickel-cobalt-native silver deposits, Black Hawk District, Grant County, New Mexico: U.S. Geological Survey Bulletin 1009-K, 283-311.
Givens, D.B., 1951, A new basic copper phosphate mineral (chinoite) from Santa Rita, New Mexico: University of New Mexico, unpublished Master's thesis.
Graeme, D.L., and Graeme, R.W., IV, 1983a, The Philadelphia Mine: New Mexico Geology, v. 5, no. 4, p. 84.
Graf, D.L., 1949, Trace-element studies, Santa Rita, New Mexico: New York, Columbia University, unpublished Ph. D. dissertation.
Greet, C.B., 1987, A stratigraphic and petrographic analysis of the "Abo" Formation in the Santa Rita, New Mexico, area: Stephen F. Austin State University, unpublished Master's thesis,

95 p.

Geeslin, J.H., 1980, Petrography of the Aleman Formation, Upper Ordovician, Silver City Range, southwestern New Mexico: Houston, Tex., University of Houston, unpublished Master's thesis.

Gerwe, J.E., 1986, Ag-Ni-Co-As-U mineralization in the Black Hawk Mining District, Grant County, New Mexico: Socorro, New Mexico Institute of Mining and Technology, unpublished Master's thesis, 85 p.

Gerwe, J.E., and Norman, D.I., 1985, Ag-Ni-Co-U mineralization in the Black Hawk mining district, Grant county, New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 199, p. 52.

Giancola, D., ed., 1994, American Mines Handbook: Southern Magazine and Information Group, British Columbia, Canada, 376 p.

Gillerman, Elliot, 1964, Mineral deposits of western Grant County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 83, 213 p.

Gillerman, Elliot, and Whitebread, D.H., 1956, Uranium-bearing nickel-cobalt-native silver deposits, Black Hawk District, Grant County, New Mexico: U.S. Geological Survey Bulletin 1009-K, 283-311.

Harrer, C.M., and Kelly, F.J., 1963, Reconnaissance of iron resources in New Mexico: U.S. Bureau of Mines, Information Circular 8190, 112 p.

Hedlund, D.C., 1985a, Geology, mines, and prospects of the Tyrone stock and vicinity, Grant County, New Mexico: U.S. Geological Survey Open-File Report OF 85-232, 31 p.

Hernon, R.M., compiler, 1949, Geology and ore deposits of Silver City region, New Mexico: West Texas Geological Society and Southwestern New Mexico Section, American Institute of Mining and Metallurgical Engineers, Guidebook, Field Trip no. 3, 45 p.

Hill, G.T., 1994, Geochemistry of southwestern New Mexico fluorite deposits with possible base and precious metals exploration significance: Socorro, New Mexico Institute of Mining and Technology, M.S. thesis, 44 p.

Hillesland, L.L., Worthington, W.T., and Hawkins, R.B., 1994, General geology of the Continental mine, Grant County, New Mexico; in Trip 10 and 13; Tyrone, Piños Altos, Chino, Continental, Central district, New Mexico: Bootprints along the Cordillera, Field Guide, 22 p.

Hodges, F., 1931, Milling methods at the Hurley plant of the Nevada Consolidated Copper Co., Hurley, New Mexico: U.S. Bureau of Mines, Information Circular 6394, 17 p.

Howard, E.V., 1963, A socioeconomic study of copper leaching at Santa Rita: Socorro, New

Mexico Institute of Mining and Technology, unpublished Master's thesis.

Johnson, K.E., 1983, Silver-nickel-cobalt-uranium mineralization and associated alteration in Black Hawk District, Grant County, New Mexico: New Mexico Geology, v. 5, no. 3, p. 66.

Jones, W.R., Hernon, R.M., and Pratt, W.P., 1961, Geologic events culminating in primary metallization in the Central mining district, Grant County, New Mexico, *in* Short papers in the geologic an hydrologic sciences: U.S. Geological Survey Professional Paper 424-C, p. C11–C16.

Jones, W.R., Hernon, R.M., and Pratt, W.P., 1961, Geologic events culminating in primary metallization in the Central mining district, Grant County, New Mexico, *in* Short papers in the geologic an hydrologic sciences: U.S. Geological Survey Professional Paper 424-C, p. C11-C16.

*Jones, W.R., Hernon, R.M., and Moore, S.L., 1967, General geology of Santa Rita quadrangle, Grant County, New Mexico: U.S. Geological Survey Professional Paper 555, 144 p.

*Jones, W.R., Moore, S.L., and Pratt, W.P., 1970, Geologic map of the Fort Bayard quadrangle, Grant County, New Mexico: U.S. Geological Survey Geologic Quadrangle Map GQ-865, 4 p., scale 1:24,000.

Kelley, V.C., 1949, Geology and economics of New Mexico iron-ore deposits: University of New Mexico Publications in Geology, no. 2, 246 p.

Kerr, P.F., Kulp, J.L., Patterson, C.M., and Wright, R.J., 1950, Hydrothermal alteration at Santa Rita, New Mexico: Geological Society of America Bulletin, v. 61, no. 4, p. 275-347.

Klein, D.P., 1987, Aeromagnetic map of the Silver City 1° x 2° quadrangle, New Mexico and Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map I-1310-D.

Landon, R.E., 1929, Metamorphism and ore deposition in the Santa Rita-Hanover-Fierro area, New Mexico: University of Chicago, unpublished Ph.D. dissertation.

Larsh, P.A., 1911, Vanadium in old silver mines of New Mexico: Engineering and Mining Journal, June 24, p. 1248.

Lasky, S.G., 1930, Geology and ore deposits of the Ground Hog Mine, Central District, Grant County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 2, 14 p.

Lasky, S.G., 1936b, Geology and ore deposits of the Bayard area, Central mining district, New Mexico: U.S. Geological Survey Bulletin 870, 144 p.

Lasky, S.G., and Hoagland, A.D., 1948, Central mining district, New Mexico, in Symposium on the geology, paragenesis and reserves of the ores of lead and zinc: 18th International Geological Congress, London, p. 86-97.

Lasky, S.G., and Wootton, T.P., 1933, The metal resources of New Mexico and their economic features: New Mexico Bureau of Mines and Mineral Resources Bulletin 7, 178 p.

LeMone, D.V., King, W.E., and Cunningham, J.E., 1974, Pennsylvanian System of Chloride Flat, Grant County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 131, 18 p.

Leroy, P.G., 1951, Geology of the southern margin of the Santa Rita copper pit (New Mexico): New York, Columbia University, unpublished Master's thesis.

Leroy, P.G., 1953, Correlation of copper mineralization with hydrothermal alteration in the Santa Rita porphyry copper deposit (New Mexico): New York, Columbia University, unpublished Ph.D. dissertation.

Lindgren, W., Graton, L.C., and Gordon, C.H., 1910, The ore deposits of New Mexico: U.S. Geological Survey Professional Paper 68, 361 p.

Loucks, T.A., and Newell, R.A., 1978, Geology and alteration of the Chino North Pit, Santa Rita, New Mexico [abs.]: Geological Society of America Abstracts with Programs, v. 10, no. 3, p. 114.

Lueth, V.W., 1984, Comparison of copper skarn deposits in the Silver City mining region, southwestern New Mexico: El Paso, University of Texas, unpublished Master's thesis.

McAnulty, W.N., 1978, Fluorspar in New Mexico: New Mexico Bureau of Mines and Mineral Resources Memoir 34, 64 p.

McDowell, F.W., 1971, K-Ar ages of igneous rocks from the western United States: Isochron/West, no. 2, p. 1-16.

McKnight, J.F., and Fellows, M.L., 1978, Silicate mineral assemblages and their relationship to sulfide mineralization, Piños Altos mineral deposit, New Mexico, *in* Jenney, J.P., and Hauck, H.R., eds., Proceedings of the porphyry copper symposium: Arizona Geological Society Digest, v. 11, p. 1-8.

McLemore, V.T., 1994b, Placer gold deposits in New Mexico: New Mexico Geology, v. 16, p. 21-25.

McLemore, V.T., 1995 (in press), Volcanic-epithermal precious-metal deposits in New Mexico, *in* Geology and ore deposits of the American Cordillera: Geological Society of Nevada.

McOwen, L.K., 1993, The Brock Canyon volcanic complex, Grant County, New Mexico--Volcanic evolution, alteration, and mineralization: Tucson, University of Arizona Master's

thesis, 167 p.

Meinert, L.D., 1987, Skarn zonation and fluid evolution in the Groundhog Mine, Central Mining District, New Mexico: Economic Geology Bulletin no. 3, p. 523-545.

Milbauer, J.A., 1983, The historical geography of the Silver City mining region of New Mexico: Los Angeles, University of California, unpublished Ph.D. dissertation.

*Mueller, J.E., and Twidale, C.R., 1988, Landform development of City of Rocks State Park and Giant of the Mimbres, *in* Mack, F.H., Lawton, T.F., and Lucas, S.G., eds., Cretaceous and Laramide tectonic evolution of southwestern New Mexico: New Mexico Geological Society, 39th Annual Field Conference, Deming, N. Mex., p. 185-190.

Mullen, D.H., and Storms, W.R., 1948, Copper Flat zinc deposit, Central mining district, Grant County, New Mexico: U.S. Bureau of Mines Report of Investigations 4228, 8 p.

Nielsen, R.L., 1968, Hypogene texture and mineral zoning in a copper-bearing granodiorite porphyry stock, Santa Rita, New Mexico: Economic Geology, no. 1, p. 37-50.

Nielsen, R.L., 1970, Mineralization and alteration in calcareous rocks near the Santa Rita stock, New Mexico, *in* Woodward, L.A., ed., Guidebook of the Tyrone-Big Hatchet Mountains-Florida Mountains region: New Mexico Geological Society Guidebook 21, p. 133-139.

O'Neill, A.J., and Thiede, D.S., 1982, Silver City quadrangle, New Mexico and Arizona: Bendix Field Engineering Corporation, Grand Junction Operation PGJ/F-131(82), 87 p.

Ordonez, G., Baltosser, W.W., and Martin, K., 1955, Geologic structures surrounding the Santa Rita intrusive, New Mexico: Economic Geology, v. 50, p. 9-21.

Osterberg, M., and Muller, P., 1994, Geology of the Cyprus Piños Altos deposit; in Trip 10 and 13; Tyrone, Piños Altos, Chino, Continental, Central district, New Mexico: Bootprints along the Cordillera, Field Guide, 29 p.

Paige, Sidney, 1910, The ore deposits near Piños Altos, New Mexico, in Contributions to Economic Geology, Pt. 1, Metals and nonmetals except fuels: U.S. Geological Survey Bulletin 470, p. 109-124.

Paige, Sidney, 1916, Description of the Silver City quadrangle, New Mexico: U.S. Geological Survey Geologic Atlas of the United States, Folio 199, 19 p.

Paige, Sidney, 1922, Copper deposits of the Tyrone district, New Mexico: U.S. Geological Survey Professional Paper 122.

Parry, W.T., Ballantyne, J.M., and Jacobs, D.C., 1984, Geochemistry of hydrothermal sericite from Roosevelt Hot Springs and the Tintic and Santa Rita porphyry copper systems: Economic Geology and the Bulletin of the Society of Economic Geologists, v. 79, no. 1, p. 72-86.

Patterson, C.M., 1947, Alteration in the Santa Rita copper deposits, Santa Rita, New Mexico: New York, Columbia University, unpublished Ph. D. dissertation .

Pitts, P.D., 1949, Temperature relations at Oswaldo Mine, Santa Rita, New Mexico: University of Toronto, unpublished Master's thesis.

Pratt, W.P., 1967, Geology of the Hurley West quadrangle, Grant County, New Mexico: U.S. Geological Survey Bulletin 1241-E, p. E1-E91.

Pratt, W.P., and Jones, W.R., 1961, Montoya Dolomite and Fusselman Dolomite in Silver City region, New Mexico: American Association of Petroleum Geologists Bulletin, v. 45, p. 484-500.

Raines, G.L., 1984, Preliminary map showing limonitic areas in the Silver City 1°x2° quadrangle, Arizona and New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map MF-1183-Q, scale 1:250,000.

Ratté, J.C., Gaskill, D.L., Eaton, G.P., Peterson, D.L., Stotelmeyer, R.B., and Meeves, H.C., 1979, Mineral resources of the Gila Primitive Area and Gila Wilderness, New Mexico: U.S. Geological Survey Bulletin 1451, 229 p.

Raup, R., 1952, Relationship between zinc ores and gossan at Hanover, New Mexico: Ann Arbor, University of Michigan, unpublished Master's thesis.

Reynolds, T.J., and Beane, R.E., 1985, Evolution of hydrothermal fluid characteristics at the Santa Rita, New Mexico, porphyry copper deposit: Economic Geology, v. 5, p. 1328-1347.

Richter, D.H., Houser, B.B., Watts, K.C., Klein, D.P., Sharp, W.N., Drewes, H.D., Hedlund, D.C., Raines, G.L., and Hassemer, J.R., 1987, The Conterminous United States Mineral Assessment Program--Background information to accompany folio of geologic and mineral resource maps of the Silver City 1° x 2° quadrangle, New Mexico and Arizona: U.S. Geological Survey Circular 0975, 22 p.

Richter, D.H., and Lawrence, V.A., 1983, Mineral deposit map of the Silver City 1° x 2° quadrangle, New Mexico and Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map I-1310-B, 70 p.

Richter, D.H., and Sharp, W.N., 1984, Mineral resource potential of the Silver City 1° x 2° quadrangle, New Mexico-Arizona; Map A, Geologic map: U.S. Geological Survey Open-File Report 84-0629-A.

Richter, D.H., and Sharp, W.N., 1984, Mineral resource potential of the Silver City 1° x 2° quadrangle, New Mexico-Arizona; Map B, Copper resource potential: U.S. Geological Survey Open-File Report 84-0629-B.

Richter, D.H., and Sharp, W.N., 1984, Mineral resource potential of the Silver City 1° x 2° quadrangle, New Mexico-Arizona; Map C, Molybdenum resource potential: U.S. Geological Survey Open-File Report 84-0629-C.

Richter, D.H., and Sharp, W.N., 1984, Mineral resource potential of the Silver City 1° x 2° quadrangle, New Mexico-Arizona; Map D, Zinc and lead resource potential: U.S. Geological Survey Open-File Report 84-0629-D.

Richter, D.H., and Sharp, W.N., 1984, Mineral resource potential of the Silver City 1° x 2° quadrangle, New Mexico-Arizona; Map E, Gold and silver resource potential: U.S. Geological Survey Open-File Report 84-0629-E.

Richter, D.H., and Sharp, W.N., 1984, Mineral resource potential of the Silver City 1° x 2° quadrangle, New Mexico-Arizona; Map F, Tin resource potential: U.S. Geological Survey Open-File Report 84-0629-F.

Richter, D.H., and Sharp, W.N., 1984, Mineral resource potential of the Silver City 1° x 2° quadrangle, New Mexico-Arizona; Map G, Iron, nickel, and cobalt resource potential: U.S. Geological Survey Open-File Report 84-0629-G.

Richter, D.H., and Sharp, W.N., 1984, Mineral resource potential of the Silver City 1° x 2° quadrangle, New Mexico-Arizona; Map H, Manganese and manganese-iron resource potential: U.S. Geological Survey Open-File Report 84-0629-H.

Richter, D.H., and Sharp, W.N., 1984, Mineral resource potential of the Silver City 1° x 2° quadrangle, New Mexico-Arizona; Map I, Tungsten and beryllium resource potential: U.S. Geological Survey Open-File Report 84-0629-I.

Richter, D.H., and Sharp, W.N., 1984, Mineral resource potential of the Silver City 1° x 2° quadrangle, New Mexico-Arizona; Map J, Uranium resource potential: U.S. Geological Survey Open-File Report 84-0629-J.

Richter, D.H., and Sharp, W.N., 1984, Mineral resource potential of the Silver City 1° x 2° quadrangle, New Mexico-Arizona; Map K, Fluorite resource potential: U.S. Geological Survey Open-File Report 84-0629-K.

Richter, D.H., and Sharp, W.N., 1984, Mineral resource potential of the Silver City 1° x 2° quadrangle, New Mexico-Arizona; Map L, Zeolites and diatomite resource potential: U.S. Geological Survey Open-File Report 84-0629-L.

Richter, D.H., and Sharp, W.N., 1984, Mineral resource potential of the Silver City 1° x 2° quadrangle, New Mexico-Arizona; Map M, Area in which resource potentials are designated; area in which no resource potential is designated: U.S. Geological Survey Open-File Report 84-0629-M.

Richter, D.H., Sharp, W.N., Watts, K.C., Raines, G.L., Houser, B.B., and Klein, D.P., 1983, Mineral resource assessment of the Silver City 1° x 2° quadrangle, New Mexico: U.S. Geological Survey Open-File Report 83-0924.

Richter, D.H., Sharp, W.N., Watts, K.C., Raines, G.L., Houser, B.B., and Klein, D.P., 1986, Maps showing mineral resource assessment of the Silver City 1° x 2° quadrangle, New Mexico and Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map 1310-F.

Rose, A.W., and Baltosser, W.W., 1966, The porphyry copper deposit at Santa Rita, New Mexico, *in* Titley, S.R., and Hicks, C.L., eds., Geology of porphyry copper deposits: University of Arizona Press, p. 205-220.

Rossin, E.L., 1924, Petrography of a contact metamorphic deposit near Hanover, New Mexico: New York, Columbia University, unpublished Master's thesis.

Rothrock, H.E., Johnson, C.H., and Hahn, A.D., 1946, Fluorspar resources of New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 21, 239 p.

Russell, P.L., 1947a, Steeple Rock zinc-lead district, Grant County, New Mexico: U.S. Bureau of Mines RI 4073, 13 p.

Sayala, D., 1972, A geochemical study of elemental distribution in ores and limestones from New Jersey zinc mines, Hanover, New Mexico: University of New Mexico, unpublished Master's thesis.

Schmitt, H.A., 1939, The Pewabic mine: Geological Society of America Bulletin, v. 50, p. 777-818.

Sharp, R.R., Morris, W.A., and Aamodt, P.L., 1978, Uranium hydrogeochemical and stream sediment reconnaissance data release for the New Mexico portions of the Douglas, Silver City, Clifton, and Saint Johns NTMS quadrangles, New Mexico/Arizona: Los Alamos Scientific Laboratories Report 7180, 123 p.

Sharp, W.N., 1991, Petrochemistry of igneous rocks, Silver City 1° x 2° quadrangle, New Mexico and Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map I-1310-H, 7 p.

Spencer, A.C., and Paige, Sidney, 1935, Geology of the Santa Rita mining area, New Mexico: U.S. Geological Survey Bulletin 859.

Sully, J.M., 1908, Report on property of Santa Rita Company situated in Grant County, New Mexico: unpublished report on file at New Mexico Bureau of Mines and Mineral Resources, 96 p.

Trauger, F.D., 1965, Geologic structure pattern of Grant County, New Mexico, *in* Fitzsimmons,

J.P., and Lochman-Balk, Christina, eds., Guidebook of southwestern New Mexico II: New Mexico Geological Society, 16th Field Conference, p. 184-187.

Turner, D.R., and Bowman, J.R., 1988, Modeling of temperature-fluid flow regimes in the Empire Zn-skarns, Hanover, N. Mex. [abs]: Geological Society of America Abstracts with Programs, v. 20, no. 7, p. 93.

Von Bargen, D.J., 1979, The silver-antimony-mercury system and the mineralogy of the Black Hawk District, New Mexico: Purdue University, unpublished Ph. D. dissertation, 260 p.

Von Bargen, D.J., 1993, Minerals of the Black hawk district, New Mexico: Rocks and Minerals, v. 68, no. 2, p. 96-111, 132-133.

Waldschmidt, W. A., and Lloyd, E. R., eds., 1949, Geology and ore deposits of Silver City Region, New Mexico: West Texas Geological Society and Southwestern New Mexico Section, American Institute of Mining and Metallurgical Engineers Guidebook, Field trip no. 3, 45 p.

Watts, K.C., 1981 (1982), Geochemical anomalies, Silver City 1° x 2° quadrangle, Arizona, New Mexico, *in* Geological Survey research 1981: U.S. Geological Survey Professional Paper, p. 15-16.

Watts, K.C., Carpenter, R.H., Chao, T.T., Hassemer, J.R., and Sanzolone, R.F., 1983, Comparison of secondary Fe-Mn oxides in fracture coatings and heavy-mineral concentrates as sampling media, Silver City mining region, New Mexico: Mining Engineering, v. 35, no. 8, p. 1177-1184.

Watts, K.C., and Hassemer, J.R., 1980, Distribution and abundance of fluorite in stream-sediment concentrates, Silver City 1° x 2° quadrangle, Arizona and New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map MF–1183-C.

Watts, K.C., and Hassemer, J.R., 1988, Geochemical interpretative and summary maps, Silver City 1° x 2° quadrangle, New Mexico and Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map I-1310-E.

Watts, K.C., Hassemer, J.R., Forn, C.L., and Siems, D.F., 1986, Geochemical maps showing distribution and abundance of barium in two fractions of stream-sediment concentrates, Silver City 1° x 2° degree quadrangle, New Mexico and Arizona: U.S. Geological Survey Miscellaneous Field Studies Map MF-1183-K.

Watts, K.C., Hassemer, J.R., Forn, C.L., and Siems, D.F., 1986, Geochemical maps showing distribution and abundance of bismuth in two fractions of stream-sediment concentrates, Silver City 1° x 2° quadrangle, New Mexico and Arizona: U.S. Geological Survey Miscellaneous Field Studies Map MF-1183-H.

Watts, K.C., Hassemer, J.R., Forn, C.L., and Siems, D.F., 1986, Geochemical maps showing distribution and abundance of copper in two fractions of stream-sediment concentrates, Silver City 1° x 2° quadrangle, New Mexico and Arizona: U.S. Geological Survey Miscellaneous Field Studies Map MF-1183-B.

Watts, K.C., Hassemer, J.R., Forn, C.L., and Siems, D.F., 1986, Geochemical maps showing distribution and abundance of lead in two fractions of stream-sediment concentrates, Silver City 1° x 2° quadrangle, New Mexico and Arizona: U.S. Geological Survey Miscellaneous Field Studies Map MF-1183-A.

Watts, K.C., Hassemer, J.R., Forn, C.L., and Siems, D.F., 1986, Geochemical maps showing distribution and abundance of manganese in two fractions of stream-sediment concentrates, Silver City 1° x 2° quadrangle, New Mexico and Arizona: U.S. Geological Survey Miscellaneous Field Studies Map MF-1183-J.

Watts, K.C., Hassemer, J.R., Forn, C.L., and Siems, D.F., 1986, Geochemical maps showing distribution and abundance of molybdenum in two fractions of stream-sediment concentrates, Silver City 1° x 2° quadrangle, New Mexico and Arizona: U.S. Geological Survey Miscellaneous Field Studies Map MF-1183-E.

Watts, K.C., Hassemer, J.R., Forn, C.L., and Siems, D.F., 1986, Geochemical maps showing distribution and abundance of silver in two fractions of stream-sediment concentrates, Silver City 1° x 2° quadrangle, New Mexico and Arizona: U.S. Geological Survey Miscellaneous Field Studies Map MF-1183-F.

Watts, K.C., Hassemer, J.R., Forn, C.L., and Siems, D.F., 1986, Geochemical maps showing distribution and abundance of tin in two fractions of stream-sediment concentrates, Silver City 1° x 2° quadrangle, New Mexico and Arizona: U.S. Geological Survey Miscellaneous Field Studies Map MF-1183-I.

Watts, K.C., Hassemer, J.R., Forn, C.L., and Siems, D.F., 1986, Geochemical maps showing distribution and abundance of tungsten in two fractions of stream-sediment concentrates, Silver City 1° x 2° quadrangle, New Mexico and Arizona: U.S. Geological Survey Miscellaneous Field Studies Map MF-1183-G.

Watts, K.C., Hassemer, J.R., Forn, C.L., and Siems, D.F., 1986, Geochemical maps showing distribution and abundance of zinc in two fractions of stream-sediment concentrates, Silver City 1° x 2° quadrangle, New Mexico and Arizona: U.S. Geological Survey Miscellaneous Field Studies Map MF-1183-D.

Watts, K.C., Hassemer, J.R., Siems, D.F., and Nishi, J.M., 1978, A statistical summary and listing of the spectrographic analyses of heavy mineral concentrates and conventional,

sieved stream-sediment samples, Silver City area, New Mexico: U.S. Geological Survey Open-File Report 78-0801, 247 p.

Weber, R.H., 1980, City of Rocks: New Mexico Geology, v. 2, p. 10-11.

Wright, R.J., 1947, Dike and sill alteration, Santa Rita, New Mexico: New York, Columbia University, unpublished Ph. D. dissertation.

Wunder, R.D. and Trujillo, A.D., 1987, Chino mine modernization: Mining Engineering, v. 39, no. 7, p. 867-872.

Wynn, J.C., 1981a, Complete Bouguer gravity anomaly map of the Silver City 1° x 2° quadrangle: U.S. Geological Survey Miscellaneous Investigation Series Map I-1310.

Wynn, J.C., 1981b, Principal facts for gravity stations and base-station net in the Silver City 1° x 2° quadrangle, Arizona and New Mexico: U.S. Geological Survey Open–File Report 81-0040, 141 p.

Yousefpour, M.V., 1978, Geology and contact pyrometasomatic ore deposits at the Continental Mine, Fierro, New Mexico: Golden, Colorado School of Mines, unpublished Master's thesis.

Yousefpour, M.V., 1980, Genesis of skarn polymetallic deposits in the Hanover-Fierro area and a geotechnical evaluation of pit slope stability at the Continental Mine, Fierro, New Mexico: Golden, Colorado School of Mines, unpublished Ph. D. dissertation.

SUMMIT AND BIG LUE MOUNTAINS, SAN FRANCISCO CANYON, AND MULE CREEK AREAS

by V.T. McLemore, NMBMMR

Summit Mountains, Big Lue Mountains, and Mule Creek area are in northwestern and west-central Grant County. Summit Mountains, adjacent to the Mogollon-Datil volcanic field, includes the Steeple Rock mining district. Mule Creek area lies north of the Steeple Rock district and includes the San Francisco prospects and the Hells Hole WSA in the Big Lue Mountains.

General Geology

The Summit Mountains and Mule Creek areas are situated in the transition between the Colorado Plateau to the north and the Basin-and-Range province to the south and west. The prominent northwest-trending structures that subparallel the west–northwest– trending Texas lineament zone of Wertz (1970a,b), Lowell (1974), Chapin and others (1978), and Muehlberger (1980). The Summit Mountains are on the northern edge of the Texas lineament zone and on the northwestern edge of the Burro uplift.

The oldest rocks in the immediate vicinity of the Summit Mountains are Proterozoic in age. Small exposures of coarse-grained, locally porphyritic weathered granite occur in the Riley Peaks

area south of Steeple Rock (Morrison, 1965). The granite is similar to Proterozoic granite exposed in the Burro Mountains and in the Redrock area. Granite in the Burro Mountains has been dated as 1,445-1,600 m.y. (Stacey and Hedlund, 1983). The granite in the Riley Peaks area, which probably underlies the Summit Mountains, may be of the same age.

Cretaceous sedimentary rocks unconformably overlie Proterozoic granite in the Riley Peaks area. The oldest unit is the Beartooth Quartzite, which is conformably overlain by the Colorado Formation. Virden Formation crops out near Riley Peaks. Exposed Cretaceous-Paleocene rocks are probably less than 300 m thick in the Riley Peaks area (Morrison, 1965; Hedlund, 1990b).

This region is highly fractured and faulted; stratigraphic relations are only partially preserved. The oldest volcanic rocks crop out in the southernmost portion of the Summit Mountains and decrease in age to the north and northeast (Hedlund, 1990a, b, c, 1993; Ratté and Hedlund, 1981; Biggerstaff, 1974; McLemore, 1993). Volcanic rocks range from about 34 m.y. to younger than 18 m.y. The volcanic stratigraphy of this area consists generally of successive periods of basaltic andesite, andesite, and dacite volcanic rocks with rhyolitic interbeds in a succession about 2,000-4,000 m thick. At least four ash-flow tuffs were erupted from distal calderas. Outflow sheets extend as far as the Steeple Rock area and are stratigraphic markers in the Summit and Big Lue Mountains.

The oldest volcanic rocks exposed in the Summit Mountains area are the older volcanic rocks of Steeple Rock and Mt. Royal; they are about 34 m.y. old. Biggerstaff (1974) calls these rocks the Steeple Rock group, whereas Hedlund (1990a) refers to them as a series of andesites, rhyolites, and tuffs with specific names or designations (e.g., andesite of Mt. Royal, rhyolite of Mud Springs). These older flows vary in thickness but appear uniform in composition. A series of ash-flow tuffs interlayered with Mt. Royal andesite and Mud Springs rhyolite crop out south of Steeple Rock (Hedlund, 1990a). These tuffs are less than 50 m thick and contain lithic fragments of andesite and andesite porphyry.

Steeple Rock rhyolite (Steeple Rock flow of Biggerstaff, 1974) is a prominent, massive rhyolite flow or dome up to 61 m thick that covers much of the Mt. Royal and Steeple Rock areas (McLemore, 1993). Steeple Rock rhyolite (Marvin and others, 1988; Hedlund, 1990b) unconformably overlies older sedimentary rocks and the andesite of Mt. Royal, and is unconformably overlain by the Summit Mountains formation.

Summit Mountains formation consists of lava flows, breccias, and volcaniclastic sedimentary rocks. Intrusive andesite of the Summit Mountains formation crops out near New Seep windmill.

Davis Canyon Tuff is a distinctive outflow sheet derived from the Bursum caldera in the Mogollon Mountains northeast of the study area (Ratté and others, 1984; Hedlund, 1990a). It crops out in the Summit Mountains east of Steeple Rock and the Steeple Rock mining district is its southwestern extent (McIntosh and others, 1990b; McLemore, 1993). Lithic fragments of andesite up to several cm in diameter are common; andesite, rhyolite, and tuff boulders up to one m in diameter are present locally.

Bloodgood Canyon Tuff is exposed in the Summit and Big Lue Mountains. The ash-flow tuff is characterized by round "eyes" of sanidine and bipyramidal quartz (Ratté and others, 1984; Hedlund, 1990a,b,c, 1993). This unit was mapped as Noah Mesa tuff by Wahl (1980) and younger ash-flow units were mapped as Bloodgood Canyon tuff (Hedlund,1990a,b,c; 1993). Bloodgood Canyon Tuff, probably one of the most widespread ash-flow tuffs in the Mogollon-Datil volcanic field, extends from the Bursum caldera northward to Aragon, as far south as a few km south of Steeple Rock, as far west as Clifton, and as far east as Beaverhead (McIntosh and others, 1990a,b).

A series of ash-flow tuffs occur at or near the base of the Dark Thunder Canyon formation (McLemore, 1993). These tuffs can be distinguished from one another and from the Bloodgood Canyon Tuff primarily by paleomagnetic analyses; they typically have a normal paleomagnetic direction as opposed to the reversed paleomagnetic direction characteristic of the Bloodgood Canyon Tuff. Paleomagnetic evidence suggests that several tuff units were emplaced within a short time period. Tuff commonly forms ridges and hill tops, and volcanic epithermal veins cut the tuff unit in the Steeple Rock district.

Dark Thunder Canyon formation (basaltic and andesitic rocks of Dark Thunder Canyon of Hedlund, 1990a,c, 1993), as much as 800 m thick, consists of multiple andesitic to basaltic andesite flows with interbedded younger ash-flow tuffs and volcaniclastic sandstone units (Griggs and Wagner, 1966; Biggerstaff; 1974). Individual lava flows are typically uniform in composition and range up to 15 m in thickness. Lithic fragments of andesite and andesite porphyry up to 0.8 m in diameter are common. The unit is unconformably overlain by lava flows of Crookson Peak.

Rhyolite of Hells Hole crops out north of the Summit Mountains in the Hells Hole area and eastern Big Lue Mountains. It is an intrusive-extrusive rhyolite dome at least 400 m thick that is exposed over 75 km^2 (Ratté and Hedlund, 1981; Ratté and Brooks, 1983). The unit is composed of a massive, banded flow unit, a pyroclastic facies, and a breccia facies. Satellitic volcanic plugs indicate that it may be thicker in the subsurface.

Lava flows of Crookson Peak [the brown andesite porphyry unit of Biggerstaff (1974) and Griggs and Wagner (1966)] consists of dacitic to andesitic lava flows, and forms prominent

southwest-facing cliffs on the eastern border of the Steeple Rock district from Apache Box southward to Crookson and Juniper Peaks. Maximum thickness is approximately 460 m (Hedlund, 1990b,c).

Rhyodacite of Willow Creek [rhyodacite porphyry of Willow Creek of Hedlund (1990c)] crops out north of the Foothills fault in the northwestern portion of the Steeple Rock area. It is a foliated rhyodacite flow.

Intrusive andesite of Tillie Hall Peak forms a small stock of approximately 10 km^2 north of Tillie Hall Peak (Ratté and Hedlund, 1981; Ratté and Brooks, 1983). The 24–m.y.-old unit is porphyritic and intrudes older andesites of Pine Cienega Peak. (Ratté and Hedlund, 1981). It hosts the Telluride mine.

North of the Steeple Rock area, andesitic lavas of Pine Cienega Peak in the Hells Hole area overlie the rhyolite of Hells Hole. Dacitic lavas of Maverick Hill and Mullen Peak overlie the Pine Cienega Peak flows. Andesitic lavas of Brushy Mountain overlie the Maverick Hill and Mullen Peak lavas (Ratté and Hedlund, 1981; Ratté and Brooks, 1983).

Numerous rhyolite dikes, flows and(or) domes and associated, locally derived, ash-flow tuffs are present throughout the Summit and Big Lue Mountains. These units consist of foliated to flow-banded and locally brecciated rhyolite flows and domes. In places, they are associated with ash-flow tuffs and (or) small zones of pyroclastic air-fall deposits. Thickness of the ash-flow tuffs, flows, and air-fall deposits probably does not exceed 250 m, except near vents. Most intrusive rocks appear to be fault-controlled. Some rhyolite dikes, domes, and plugs are cut by faults and younger rhyolite intrusives and some are emplaced along faults. Rhyolite features north of Steeple Rock record several intrusive events ranging in age from 27-18 m.y.

Apache Box rhyolite complex north of the Steeple Rock district consists of a series of rhyolite plugs and dikes, some vertically flow-banded. These rhyolites have intruded Dark Thunder Canyon formation rocks and the lava flows of Crookson Peak (Hedlund, 1990c; Ratté and Hedlund, 1981). Numerous rhyolite dikes, probably from the same source (Biggerstaff, 1974), extend southward from Vanderbilt Peak where they become part of the Piñon Mountains rhyolite plug and form dike swarms around Vanderbilt Peak. Most plugs and dikes occur along faults; some are offset by younger faulting. Ash-flow tuffs and volcanic breccia deposits surround some of the plugs, suggesting that the plugs may have breached the surface, producing pyroclastic deposits.

In the Piñon Mountains, a large rhyolite plug intrudes the Summit Mountains formation and Bloodgood Canyon Tuff. Rhyolite dikes extenidng to the northwest and southeast are probably related to this intrusion. A rhyolite dike or plug forms the prominent peak at Twin Peaks (Twin

Peaks rhyolite). Nearby dikes may be genetically related.

Rhyolite of Mule Creek consists of a rhyolite flow and pyroclastic member (Ratté and Hedlund, 1981; Ratté and Brooks, 1983) The flow is light-colored and flow-banded; the pyroclastic member consists of ash-flow tuffs, air-fall tuffs, and minor volcaniclastic units.

Small dikes of altered diabase less than one m wide are found locally in the Steeple Rock area. One or more dikes occur in the vicinity of Twin Peaks (Biggerstaff, 1974), near Summit Peak, near the Rattlesnake mines (west of Charlie Hill), and north of the Carlisle mine.

Quaternary units include poorly bedded Gila Group (moderately indurated fanglomerate as much as 300 m thick; Hedlund, 1993), alluvial fan deposits containing sheet-floodplain deposits as much as 85 m thick (Hedlund, 1990 a,b,c), unconsolidated alluvial gravels probably less than 4 m thick, and sinter or spring deposits less than 8 m thick [in Bitter Creek (sec. 20, T. 16 S., R. 21 W.)]. The soft, friable, unconsolidated sinter consists of gypsum, amorphous silica, and calcareous clay.

At least three lineaments occur in the vicinity of Steeple Rock (**figure 1-4**). Texas lineament is a prominent 80-150 km-wide zone that is defined by basins, ranges, and structural features (Lowell, 1974; Wertz, 1970a,b; Turner, 1962; Schmitt, 1966; Drewes, 1991). Dip-slip (normal, reverse, or thrust) movements are common throughout this zone, and strike-slip (horizontal) movement has been documented locally (Turner, 1962; Wertz, 1970 a,b; Muehlberger, 19870). Steeple Rock mining district lies on the northeastern edge of the Texas lineament zone.

The prominent northeast-trending Morenci lineament, which can be traced from Safford AZ northeast to Reserve NM, lies north of Steeple Rock. Steeple Rock area includes the Morenci uplift of Cather and Johnson (1986), and the Safford and Morenci porphyry copper deposits. Epithermal silver-gold deposits of the Mogollon district lie on the southern edge of the lineament (Lowell, 1974; Chapin and others, 1978).

A third, less well-documented lineament occurs south of the Steeple Rock district and is known as the New Mexico mineral belt (Lowell, 1974) or the Santa Rita lineament (Chapin and others, 1978). This lineament includes the Cananea, Bisbee, Santa Rita, and Tyhrone porphyry copper deposits and numerous smaller epithermal districts (Lowell, 1974). It is defined by Laramide intrusives and northeast-trending faults (Rose and Boltosser, 1966).

References

(* reference used in writing above summary)

*Biggerstaff, B.P., 1974, Geology and ore deposits of the Steeple Rock-Twin Peaks area, Grant County, New Mexico: El Paso, University of Texas, unpublished Master's thesis, 102 p.

Chapin, C.E., Siemers, W.T., and Osburn, G.R., 1975, Summary of radiometric ages of New

Mexico rocks: New Mexico Bureau of Mines and Mineral Resources Open File Report 60, extensive compilation kept up to date [inspection only at NMBMMR].

*Griggs, R.L., and Wagner, H.C., 1966, Geology and ore deposits of the Steeple Rock mining district, Grant County, New Mexico, *in* Contributions to Economic Geology: U.S. Geological Survey Bulletin 1222E, p. 29.

*Hedlund, D.C., 1990a, Geology and mineral deposits of the Steeple Rock and Duncan mining districts, Grant and Hidalgo Counties, New Mexico, and Greenlee County, Arizona: U.S. Geological Survey Open-File Report 90-239, 27 p.

*Hedlund, D.C., 1990b, Geologic map and sections of the Steeple Rock quadrangle, Grant and Hidalgo Counties, New Mexico, and Greenlee County, Arizona: U.S. Geological Survey Open-File Report 90-240, scale 1:24,000, 14 p.

*Hedlund, D.C., 1990c, Preliminary geologic map and sections of the Walker Canyon quadrangle, Grant and Hidalgo Counties, New Mexico: U.S. Geological Survey Open-File Report 92-531-M.

*Hedlund, D.C., 1993, Geologic map of the Tillie Hall Peak quadrangle, Greenlee County, Arizona, and Grant County, New Mexico: U.S. Geological Survey Geologic Quadrangle Map GQ-1715, scale 1:24,000.

Marvin, R.F., Mehnert, H.H., and Naeser, C.W., 1988, U.S. Geological Survey radiometric ages—compilation "C", Pt. 2; Arizona and New Mexico: Isochron/West, no. 51, p. 5-13.

*Morrison, R.B., 1965 [1966], Geologic map of the Duncan and Canador Peak quadrangles, Arizona and New Mexico: U.S. Geological Survey Miscellaneous Investigations Series Map I-0442, scale 1:48,000.

Lowell, J.D., 1974, Regional characteristics of porphyry copper deposits of the southwest: Economic Geology, v. 69, no. 5, p. 601-617.

*McLemore, V.T., 1993b, Geology and geochemistry of the mineralization and alteration in the Steeple Rock district, Grant County, New Mexico and Greenlee County, Arizona. El Paso, University of Texas, Ph. D dissertation, 525 p. (NMBMMR Open-file report 397).

*McLemore, V.T., and Clark, K.R., 1993, Alteration and epithermal mineralization int he Steepl e Rock mining district, Grant County, New Mexico and Greenlee County, Arizona [abs.], Conference Program and extended abstracts, Integrated Methods in Exploration and Discovery, Society of Economic Geologists, p. AB 69-70.

Muehlberger, W.R., 1980, Texas lineament revisited; *in* Dickerson, P.W., Hoffer, J.M., and Callender, J. F., eds., Trans-Pecos region (west Texas): New Mexico Geological Society, 31st Annual Field Conference, Guidebook, p. 113-121.

*Powers, R.S., 1976, Geology of the Summit Mountains and vicinity, Grant County, New Mexico and Greenlee County, Arizona: Houston, Tex., University of Houston, unpublished Master's thesis, 107 p.

*Ratté, J.C., and Brooks, W.E., 1983, Geologic map of the Mule Creek quadrangle, Grant County, New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map MF-1666.

*Ratté, J.C., and Hedlund, D.C., 1981, Geologic map of the Hells Hole further planning area (RARE II), Greenlee County, Arizona, and Grant County, New Mexico: U.S. Geological Survey Map MF-1344-A, scale 1:62,000.

*Ratté, J.C., and Lane, M.E., 1984, Lower San Francisco Wilderness Study Area and contiguous roadless areas, Arizona and New Mexico, *in* Marsh, S.P., Kropschot, S.J., and Dickinson, R.G., eds., Wilderness mineral potential; assessment of mineral-resource potential in U.S. Forest Service lands studied 1964-1984: U.S. Geological Survey Professional Paper 1300, p. 79-82.

*Ratté, J.C., Hassemer, J.R., Martin, R.A., and Briggs, J.P., 1982, Mineral resource potential of the Hells Hole further planning area (RARE II), Greenlee County, Arizona, and Grant County, New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map MF-1344-E, 7 p.

*Ratté, J.C., Hassemer, J.R., Martin, R.A., and Lane, Michael, 1982, Mineral resource potential of the Lower San Francisco Wilderness Study Area and contiguous Roadless Area, Greenlee County, Arizona, and Catron and Grant Counties, New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map MF-1463-C, scale 1:62,500.

*Ratté, J.C., Marvin, R.F., and Naeser, C.W., 1984, Calderas and ash flow tuffs of the Mogollon Mountains, southwestern New Mexico: Journal of Geophysical Research, v. 89, no. 10, p. 8713-8732.

Richter, D.H., Lawrence, V.A., Drewes, Harald, Young, T.H., Enders, M.S., Damon, P.E., and Thorman, C.H., 1990, Geologic map of the San Simon quadrangle and parts of the Summit Hills and Mondel Quadrangles, Cochise, Graham, and Greenlee Counties, Arizona, and Hidalgo County, New Mexico: U.S. Geological Survey Miscellaneous Investigations Series Map I-1951, scale 1:48,000.

*Russell, P.L., 1947a, Steeple Rock zinc-lead district, Grant County, New Mexico: U.S. Bureau of Mines RI 4073, 13 p.

*Stacey, J.S., and Hedlund, D.C., 1983, Lead-isotopic compositions of diverse igneous rocks and ore deposits from southwestern New Mexico and their implications for early

Proterozoic crustal evolution in the western United States: Geological Society of America Bulletin, v. 94, no. 1, p. 43-57.

Wertz, J.B., 1970a, Arizona's copper province and the Texas lineament: Mining engineering, v. 5, p. 80-81.

Wertz, J.B., 1970b, The Texas lineament and its economic significance in southeastern Arizona: Economic Geology, v. 65, p. 166-181.

HIDALGO COUNTY

Hidalgo County was established in 1919 from the southwestern part of Grant County. It was named to commemorate the Treaty of Guadalupe Hidalgo, which ended the Mexican War in 1848 and ceded New Mexico, Arizona, and California to the United States. It is one of the least populated counties in New Mexico (only 1.8 persons per square mile, according to 1986 census figures; U.S. Department of Commerce, 1988); Lordsburg is the county seat and largest city.

ALAMO-HUECO-DOG MOUNTAINS

Alamo-Hueco-Dog Mountains, bounded on the west by Hachita Valley and on the east by Playas Valley in the southeastern corner of the bootheel, are within the late Paleozoic Pedregosa Basin. The northwest-trending, faulted ranges are composed of Lower Cretaceous limestone and sandstone separated from overlying Tertiary volcanic tuffs and flows by an angular conformity. The ranges form the southernmost part of a northwest trending chain of mountains with similar geology, including from north to south, the Brockman Hills, Coyote Hills, Little Hatchet Mountains, and Big Hatchet Mountains.

General Geology

The Lower Cretaceous U-Bar and Mojado Formations (in the northern part of the chain), Little Hat Top Conglomerate, and volcanic rocks from the Tullous, Juniper, Cowboy Rim, and San Luis calderas crop out in the ranges (appendix B). Tertiary units include the basaltic andesite of Emory Canyon, Bluff Creek Formation, Wood Canyon tuff, Oak Creek Tuff, Gray Ranch tuff, Gillespie Tuff, Bull Canyon basaltic andesite, Park Tuff, and Bear Creek basalt.

Pre-Laramide, Laramide, and Basin-and-Range tectonism affected the rocks of the region. Overturned asymmetric folds evidence northeast-directed thrusting adjacent to the Hidalgo uplift during Laramide events (Seager and Mack, 1986). Little Hat Top Conglomerate was deposited into Little Hat Top basin (Seager and Mack, 1986) during erosion and truncation of the Laramide folds. High-angle, range-front faulting with dip-slip movement and jointing in the rocks characterize Basin-and-Range tectonic events, which began about 30 m.y. ago. Vertical displacement on the northwest-trending faults along Black Canyon and Bear Creek may be as much as 30-60 m. Vertical displacement along northwest-trending range-front faults on the flanks of the Dog Mountains is as much as 458 m. No Quaternary fault movement has been described from the Alamo-Hueco-Dog Mountains.

Mineral Deposits

The Antelope Wells-Dog Mountains mining district is in the Alamo-Hueco-Dog Mountains. Extensive travertine deposits with associated manganese occur in the tuff of Bluff Creek Canyon in the southern part of the area (Reiter, 1980). Two travertine beds, each about one meter thick, are

separated by a thin sandstone unit. Psilomelane bands up to one inch thick form the lowermost parts of the travertine. Prospect pits have developed the deposit, but production, if any, is unknown. Guano is found in a cave in sec. 16, T. 33 S., R. 14 W. (Reiter, 1980).

Petroleum potential may be present owing to the proximity with the Pedregosa Basin. One well drilled in the area (Humble No. 1 State BA well; $NE^1/_4$ sec. 25, T. 32 S., R. 16 W.) encountered gas and oil shows.

References

(* reference used in writing above summary)

Deal, E.G., Elston, W.E., Erb, E.E., Peterson, S.L., Reiter, D.E., Damon, P.E., and Shafiqullah, M., 1978, Cenozoic volcanic geology of the Basin and Range province in Hidalgo County, southwestern New Mexico, *in* Callender, J.F., Wilt, J.C., and Clemons, R.E., eds., Land of Cochise, Southeastern Arizona: New Mexico Geological Society, *in cooperation with* Arizona Geological Society, 29th Field Conference, p. 219-229.

*Everhart, D.L., 1957, Uranium-bearing veins in the U.S., *in* Contributions to the geology of uranium and thorium: U.S. Geological Survey Professional Paper 300, p. 97-104.

*Farnham, L.L., 1961, Manganese deposits of New Mexico: U.S. Bureau of Mines Information Circular 8030, 36 p.

*McLemore, V.T., 1982, Radioactive occurrences in veins and igneous and metamorphic rocks of New Mexico with annotated bibliographic: New Mexico Bureau of Mines and Mineral Resources Open File Report 155, 267 p.

*McLemore, V.T., 1983a, Uranium industry in New Mexico; history, production, and present status: New Mexico Geology, v. 5, no. 3, p. 45-51.

*McLemore, V.T., 1983b, Uranium and thorium occurrences in New Mexico--Distribution, geology, production, and resources, with selected bibliography: New Mexico Bureau of Mines and Mineral Resources Open File Report 183, 180 p.

*North, R.M., and McLemore, V.T., 1986, Silver and gold occurrences in New Mexico: New Mexico Bureau of Mines and Mineral Resources Resource Map 15, 32 p., scale 1:1,000,000.

*Reiter, D.F., 1980, Geology of the Alamo-Hueco and Dog Mountains, Hidalgo County, New Mexico: Albuquerque, N. Mex., University of New Mexico Master's thesis, 100 p.

*Seager, W.R., and Mack, G.H., 1986b, Laramide paleotectonics of southern New Mexico, *in* Peterson, J.A., ed., Paleotectonics and Sedimentation in the Rocky Mountain Region, United States: American Association of Petroleum Geologists Memoir 41, 669-685.

*Zeller, R.A., Jr., 1959, Reconnaissance geologic map of Dog Mountains quadrangle: New

Mexico Bureau of Mines and Mineral Resources Geologic Map 8, scale 1:62,500.

ANIMAS MOUNTAINS

Animas Mountains are located in south-central Hidalgo County, bounded by the Animas Valley on the west and the Playas Valley on the east. Cowboy Springs WSA is located in the central part of the range.

General Geology

Precambrian basement rocks in the northern Animas Mountains consist of porphyritic granite and pendants or inclusions of amphibolite or diorite (**plate 1-1**); granitic rocks have been dated at 1,200 Ma Poorly exposed and highly deformed Paleozoic and Cretaceous sedimentary rocks overlie basement rocks and are unconformably overlain by Tertiary intrusive and extrusive sequences. Paleozoic units in the Animas Mountains include the Bliss Formation, El Paso Limestone, Montoya Group (Cutter Dolomite), Percha Shale, Escabrosa Group, Horquilla Limestone, Earp Formation, Epitaph Dolomite, Paradise Formation, Colina Limestone, Scherrer Formation, Concha Limestone, and gypsum- and anhydrite-bearing units (unnamed) that may be Permian or Jurassic(?) in age. Overlying Mesozoic rocks include the Cretaceous Cintura Formation, Mojado Formation, U-Bar Formation, Hell-to-Finish Formation, Glance Conglomerate, Morita Formation, Mural Limestone, and various unnamed intrusive, volcanic, and sedimentary rocks of Cretaceous and Tertiary age deposited during and after regional Laramide tectonic events. Erosion, especially in the central higher parts of the Animas Mountains, has exposed the Paleozoic and Cretaceous rocks, numerous faults and folds, and underlying Precambrian intrusives.

Tertiary rocks are composed mostly of layered tuffs, flows, conglomerate beds, and other volcaniclastic rocks. Intrusive and volcanic rocks are mostly of silicic to intermediate (rhyolite to latite) composition. They have undergone lesser deformation than the older bedded rocks. These intrusive and volcanic units include the Bennett Spring tuff, Bluff Creek Formation, Cedar Hill Andesite, Center Peak Latite, Gillespie Tuff, Gray Ranch Tuff, Oak Creek Tuff, and Park Tuff. Intrusive plugs and volcanic centers and dikes are not exposed as well as the volcanic sequences.

Quaternary unconsolidated to weakly consolidated deposits are present in alluvial, pediment, terrace, playa, and fan settings. Pediment gravel is present mostly on the eastern side of the mountain range; alluvium is present in and adjacent to stream courses. Lacustrine deposits are associated with playas in the intermontane basins adjacent to the range. East of the range, Playas Valley is at least 335 m deep (as evidenced by water well depths reported in Zeller and Alper, 1965).

Structures in the range show evidence of a complex history of east-directed thrust faulting, rotational (extensional?) block faulting (variable in trend), and complex folding and overturning of strata. Many of the structural features indicate reactivation during the many episodes of tectonism that affected the rock sequences. For example, field evidence shows that folding of the Winkler anticline was initiated prior to Laramide events, but movement on the anticline continued until post-Tertiary time. Strongest deformation, between Early Cretaceous and Tertiary time (Laramide), is associated with sedimentation and volcanism that occurred simultaneously with faulting and formation of uplifts and basins (**figure 1-5**). Tectonism was generally east-directed, and resulted in steep to shallow dips on faults and fold axes. A later episode of faulting took place in middle Tertiary time, forming nearly vertical block faults that form a mosaic pattern in outcrop. Post-Laramide structures are mostly normal faults, intrusives related to fractures, and volcanic episodes that are superimposed on the Laramide structures and sediments (**figure 1-6**).

Calderas described from the Animas Mountains (summarized by Elston, 1984) include the Juniper, Animas Peak, Tullous, and Cowboy Rim calderas (described below). Elevation and eastward tilting of the Animas Range took place after deposition of Tertiary sediments along normal faults that flank the range. This latter period continues to the present, and may be related to extensional (Basin-and-Range) activity related to the Rio Grande Rift.

Calderas

Juniper caldera, a resurgent caldera in the Red Hill area (Deal and others, 1978), has associated post-collapse breccias. The principal ash-flow sheet is the Oak Creek Tuff, wherein the youngest and stratigraphically highest deposits contain the most silica. Moat and ring-fracture deposits are composed of the Bennett Spring tuff and the Cedar Hill Andesite. The volcano has been dated at 35 Ma (Deal and others, 1978), and the quartz monzonite stock in the subsurface is 34 Ma ($^{40}Ar/^{39}Ar$, feldspar, McLemore and others, 1995).

The Animas Peak caldera is preserved only partially, and shows little chemical zoning. The principal ash-flow sheet is the tuff of Black Bill Canyon, dated at 33 Ma. There is some evidence for potassium metasomatism of the rocks (relict replacement, wherein a new mineral replaces an old one, but keeps the form of the mineral replaced).

The Tullous caldera has been interpreted as a trap-door caldera, hinged on the east with a buried vent on the west. The caldera is filled with multiple ash-flow sheets dated at 36-37 Ma (Erb, 1979) interbedded with sediments of the Bluff Creek Formation.

The Cowboy Rim caldera, filled mainly with Gillespie Tuff, has deposits associated with quartz latite of Cowboy Rim and andesite of Center Peak (Erb, 1979). Volcanic activity has been dated at about 33 Ma (Deal and others, 1978). The Gillespie Tuff filled the Cowboy Rim caldera

to a depth of at least 915 m (Erb, 1979). Outflow is found in the southern and central Animas Mountains.

Winkler Anticline

The 5 km long and 2.5 km wide Winkler anticline, located in the central part of the Animas Mountains (secs. 3, 4, T. 31 S., R. 18 W.), was initially formed in middle Permian-Early Cretaceous time, but deformation continued into post-Tertiary time. The exposed, northeast-trending axial portion of the doubly plunging structure is composed of Horquilla Limestone surrounded by Earp Formation, Colina Limestone, Hell-to-Finish Formation/Glance Conglomerate, U-Bar/Morita Formations, Mojado Formation/Mural Limestone, Cowboy Spring Formation/Cintura Formation, and various Tertiary formations. It is truncated locally by faults and a major unconformity at the base of the Cretaceous section. The anticline is intruded by quartz monzonite of the Walnut Wells stock on the southwest. Faults that trend northeast and northwest intersect in the area of Gillespie prospect on the northwest flank of the anticline.

Mineral Deposits

Gillespie (Red Hill) and Rincon mining districts are in the Animas Mountains. About 150m of coarsely to finely crystalline marble in the Horquilla Formation was described from the KCM Forest Federal Well, Winkler anticline (Thompson and others, 1977).

Fire clay was produced in the early 1900s, and continues to be produced today, from near the Animas district. The deposits form by hydrothermal alteration of andesite within fault zones.

A well drilled into the Winkler anticline encountered neither oil nor gas. By interpretation of well logs, the lack of petroleum potential is due to excessive heat during episodes of Tertiary intrusion and subsequent metamorphism.

References

(* reference used in writing above summary)

Brooks, W.E., Adrian, B.M., and Erlich, Olga, 1988, Analytical results and sample locality map of rock samples from the Cowboy Spring Wilderness Study Area, Hidalgo County, New Mexico: U.S. Geological Survey Open-File Report 88-0211, 9 p.

*Brooks, W.E., Hassemer, J.R., Duval, J. S., Hanna, W.F., and Scott, D.C., 1989, Mineral resources of Cowboy Spring Wilderness Study Area, Hidalgo County, New Mexico: U.S. Geological Survey Bulletin 1735-F, p. F1-F11.

Cernock, P.J., 1977, Hydrocarbon source-rock evaluation study, Humble Oil and Refining Company No. 1 State BA well, Hidalgo County, New Mexico (report by Geochem Laboratories, Inc.): New Mexico Bureau of Mines and Mineral Resources Open-file Report 97, 10 p.

Cernock, P.J., and Bayliss, G.S., 1977, Organic geochemical analyses of drill cuttings from KCM No. 1 Forest Federal well, Hidalgo County, New Mexico, *in* Thompson, Sam, III, compiler, Geology, petroleum source rocks, and thermal metamorphism, in KCM No. 1 Forest Federal well, Hidalgo County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 152, p. 37-47.

*Dale, V.B., and McKinney, W.A., 1959, Tungsten deposits of New Mexico: U.S. Bureau of Mines Report of Investigations 5517, 72 p.

*Deal, E.G., Elston, W.E., Erb, E.E., Peterson, S.L., Reiter, D.E., Damon, P.E., and Shafiqullah, M., 1978, Cenozoic volcanic geology of the Basin and Range province in Hidalgo County, southwestern New Mexico, *in* Callender, J.F., Wilt, J.C., and Clemons, R.E., eds., Land of Cochise, Southeastern Arizona: New Mexico Geological Society, *in cooperation with* Arizona Geological Society, 29th Field Conference, p. 219-229.

Dellechaie, F., 1977, A geological and hydrochemical study of the Animas geothermal area, Hidalgo County, New Mexico: Geothermal Resources Council, Transactions, v. 1, p. 73-75.

Donnan, G.R., 1987, Stratigraphy and structural geology of the northern part of the northern Animas Mountains, Hidalgo County, New Mexico: Las Cruces, New Mexico State University, unpublished M.S. thesis, 121 p.

Donnan, G.T., and Wilson, G.C., 1986, Reinterpretation of structural geology of northern Animas Mountains, Hidalgo County, New Mexico: American Association of Petroleum Geologists Bulletin, v. 70, p. 344.

*Drewes, H., 1986, Geologic map of the northern part of the Animas Mountains, Hidalgo County, New Mexico: U.S. Geological Survey Miscellaneous Investigations Series Map I-1686, scale 1:24,000.

*Elston, W.E., 1960, Reconnaissance geologic map of Virden 30' quadrangle: New Mexico Bureau of Mines and Mineral Resources Geologic Map 15, scale 1:126,720.

*Elston, W.E., 1965, Mining districts of Hidalgo County, New Mexico, *in* Fitzsimmons, J.P., and Lochman-Balk, C., eds., Guidebook of southwestern New Mexico II: New Mexico Geological Society Sixteenth Field Conference, p. 210-214.

*Elston, W.E., 1984, Mid-Tertiary ash flow tuff cauldrons, southwestern New Mexico: Journal of Geophysical Research, v. 89, no. B10, p. 8733-8750.

*Elston, W.E., Erb, E.E., and Deal, E.G., 1979, Tertiary geology of Hidalgo County, New Mexico; guide to metals, industrial minerals, petroleum, and geothermal resources: New Mexico Geology, v. 1, no. 1, p. 1-6.

*Elston, W.E., Deal, E.G., and Logsdon, M.J., 1983, Geology and geothermal waters of Lightning Dock region, Animas Valley and Pyramid Mountains, Hidalgo County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 177, 44 p., scale 1:48,000.

*Elston, W.E., and Erb, E.E., 1977, Cenozoic volcano-tectonic setting of KCM No. 1 Forest Federal Well, Animas Mountains, Hidalgo County, New Mexico, *in* Thompson, Sam, III, compiler, Geology, petroleum source rocks, and thermal metamorphism in KCM No. 1 Forest Federal well, Hidalgo County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 152, p. 53-62.

*Erb, E.E., 1979, Petrologic and structural evolution of ash-flow tuff cauldrons and noncauldron related volcanic rocks in the Animas and southern Peloncillo Mountains, Hidalgo Co., New Mexico: Albuquerque, University of New Mexico, Ph. D. dissertation, 286 p.

Hazen Research, Inc., 1979, Consulting service at Mining and Milling Corporation of America, core-drilling program on the Winkler Anticline, Hachita, Hidalgo County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Open-file Report 108, 32 p.

*Lasky, S.G., and Wootton, T.P., 1933, The metal resources of New Mexico and their economic features: New Mexico Bureau of Mines and Mineral Resources Bulletin 7, 178 p.

*McAnulty, W.N., 1972, Winkler Anticline fluorspar, Hidalgo County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Target Exploration Report E-3, 7 p.

*McLemore, V.T., McIntosh, W.C., and Pease, T.C., 1995, $^{40}Ar/^{39}Ar$ age determinations of four plutons associated with mineral deposits in southwestern New Mexico: New Mexico Bureau of Mines and Mineral Resources Open File Report 410.

Scott, D.C., 1987, Mineral investigation of the Cowboy Spring Wilderness Study Area (NM-030-007), Hidalgo County, New Mexico: U.S. Bureau of Mines Open-file Report MLA 68-87, 10 p.

*Seager, W.R., and Mack, G.H., 1986, Laramide paleotectonics of southern New Mexico, *in* Peterson, J.A., ed., Paleotectonics and Sedimentation in the Rocky Mountain Region, United States: American Association of Petroleum Geologists, Memoir 41, 669-685.

*Soulé, M.M., 1972, Structural geology of northern part of Animas Mountains, Hidalgo County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 125, 15 p., map scale 1: 24,000.

*Summers, W.K., 1976, Catalog of thermal waters in New Mexico: New Mexico Bureau of Mines and Mineral Resources Hydrologic Report 4, 80 p., chemical analyses on microfiche.

*Thompson, Sam, III, 1977, Subsurface geology and the petroleum-exploration significance of KCM No. 1 Forest Federal Well, Hidalgo County, New Mexico, *in* Thompson, Sam, III, compiler, Geology, petroleum source rocks, and thermal metamorphism in KCM No. 1 Forest Federal well, Hidalgo County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 152, p. 5-23.

*Williams, F.E., 1966, Fluorspar deposits of New Mexico: U.S. Bureau of Mines Information Circular 8307, 143 p.

Wilson, G.C., 1986, Structural geology of the southern part of the northern Animas Mountains, south-central Hidalgo County, New Mexico: Las Cruces, New Mexico State University, unpublished M.S. thesis, 115 p.

*Zeller, R.A., 1959, Reconnaissance geologic map of Playas 15' quadrangle: New Mexico Bureau of Mines and Mineral Resources Geologic Map 75, scale 1:62,500.

*Zeller, R.A., Jr., 1962, Reconnaissance geologic map of southern Animas Mountains: New Mexico Bureau of Mines and Mineral Resources Geologic Map 17, scale 1:62,500.

*Zeller, R.A., and Alper, A.M., 1965, Geology of the Walnut Wells Quadrangle, Hidalgo County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 84, 105 p., scale 1:48,000.

ANIMAS VALLEY

Animas Valley, a valley graben of the Basin and Range province, is bordered by the horst blocks of the Peloncillo Mountains on the west and the Animas and Pyramid Mountains on the east.

Drill holes for oil indicate that the valley is underlain by Tertiary volcanic rock, Paleozoic sedimentary rocks, and Precambrian rocks. Surficial deposits include eolian, fluvial, fan, and playa deposits; basaltic lavas are interbedded with and overlie valley fill.

General Geology

The drainage divide between the Animas and Gila River Valleys is about 50 m above the lowest point in the Animas Valley; eventual capture by the Gila River will drain Animas Basin. The valley is the site of Pleistocene Lake Animas. Lake Animas, probably late Wisconsin in age, was about 28 km long and 6-13 km mi wide, and covered a 389 km^2 area. The highest beach bar is located at about 1,278 m elevation. Depth of the ancient lake was as much as 15 m. Sand dunes cover about 78 km^2, and border the ancient lake on the north and northeast. Dunes are as much as 18 m high and were deposited by winds from the southwest. Low ridges constitute the shoreline of the ancient lake and suggest the presence of offshore bars and barriers.

Within the valley, the high-angle normal Animas Valley fault cuts Holocene sediments

(Smith, 1978). The fault records present-day Basin-and-Range faulting and provides the conduit for hydrothermal fluids from buried plutons. Geophysical evidence (gravity and resistivity data) indicates that the fault intersects the ring-fracture system of Muir caldera.

Mineral and Energy Resources

Abundant quantities of valley deposits are potential resources for the manufacture of adobe brick. Nitrate salts have been mined in the valley.

Animas Valley is within the Lightning Dock Known Geothermal Resource Area (KGRA). A geothermal anomaly is located west of the southern Pyramid Mountains along the eastern lower Animas Valley. In 1948, cattle ranchers drilled for water in sec. 7, T. 25 S., R. 19 W., and struck steam and boiling water at less than 30 m depth (Smith, 1978). Water and steam were emanating from a 5-9–m-thick section of alluvium that was resting on lithic rhyolitic tuff. Water temperature was measured at 101.5˚C. Leasing soon followed and subsequent wells (both geothermal and oil tests) have been drilled.

Many acres are irrigated by deep wells near Animas, and geothermal energy is the source of heat for greenhouse farming on the east side of the valley. The water has high fluorine content, which may suggest an association with fluorite veins and hydrothermal manganese deposits along the Pyramid Mountain front. More likely, fluorine was leached from surfaces of glass shards in the valley fill. Fluorine is high in other basins of the Rio Grande, such as the San Luis Valley in southern Colorado (David A. Lindsey, written commun., 1996).

References

(* reference used in writing above summary)

Chaturvedi, L., and Ramos, A.M., 1979, Geothermal hydrology and hydrogeology of Animas Basin and KGRA, southwestern New Mexico: Geological Society of America Abstracts with Programs, v. 11, no. 7, p. 400-401.

Davie, W., and Spiegel, Z., 1967, Geology and water resources of Las Animas Creek and vicinity, Sierra County, New Mexico: New Mexico State Engineer, Santa Fe, Las Animas Creek Hydrographic Survey Report, 44 p.

Dellechaie, F., 1977, A geological and hydrochemical study of the Animas geothermal area, Hidalgo County, New Mexico: Geothermal Resources Council, Transactions, v. 1, p. 73-75.

*Elston, W.E., 1965, Volcanic rocks of the Mimbres and upper Gila drainages, New Mexico, *in* Fitzsimmons, J.P., and Lochman-Balk, Christina, eds., Guidebook of southwestern New Mexico II: New Mexico Geological Society, 16th Field Conference, p. 167-179.

*Elston, W.E., Deal, E.G., and Logsdon, M.J., 1983, Geology and geothermal waters of

Lightning Dock region, Animas Valley and Pyramid Mountains, Hidalgo County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 177, 44 p., scale 1:48,000.

*Fleischhauer, H.L., 1978, Summary of the late Quaternary geology of Lake Animas, Hidalgo County, New Mexico, *in* Callender, J.F., Wilt, J.C., and Clemons, R.E., eds., Land of Cochise, Southeastern Arizona: New Mexico Geological Society, 29th Field Conference, 283-284.

*Fleischhauer, H.L., Jr., and Stone, W.J., 1982, Quaternary geology of Lake Animas, Hidalgo County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 174, 25 p.

*Hawley, J.W., and Kottlowski, 1965, Road log from Lordsburg to San Simon Valley, *in* Fitzsimmons, J.P., and Lochman-Balk, Christina, eds., Guidebook of southwestern New Mexico II: New Mexico Geological Society Sixteenth Field Conference, p. 76-81.

Reeder, H.O., 1957, Ground water in Animas Valley, Hidalgo County, New Mexico: Reports Section, Technical Division, New Mexico State Engineers Office.

Schwennesen, A.T., 1918, Ground water in the Animas, Playas, Hachita, and San Luis basins, Arizona and New Mexico: U.S. Geological Survey Water–Supply Paper 422, 152 p.

*Smith, Christian, 1978, Geophysics, geology and geothermal leasing status of the Lightning Dock KGRA, Animas Valley, New Mexico, *in* Callender, J.F., Wilt, J.C., Clemons, R.E., and James, H.L., eds., Land of Cochise, southeastern Arizona: New Mexico Geological Society 29th Annual Field Conference Guidebook, p. 343-348.

BIG HATCHET MOUNTAINS

The Big Hatchet Mountains, a northwest-trending range in southeastern Hidalgo County, is bounded by the Playas Valley on the west and the Hachita Valley on the east. In southeastern Hidalgo County, the Big Hatchet Mountains contain the most complete stratigraphic section for southwestern New Mexico.

General Geology

In the Big Hatchet Mountains, quartzite and granite of Precambrian age is locally intruded by Precambrian veins. Precambrian units are unconformably overlain by Paleozoic rocks, which include Bliss Formation, El Paso Limestone, Montoya Group, Percha Shale, Escabrosa Limestone, Paradise Formation, and Naco Group (Horquilla Limestone, Earp Formation, Colina Limestone, Epitaph Dolomite, Scherrer Formation, Concha Limestone, and Rainvalley Formation).

There are no Silurian rocks in the area, and a marked unconformity exists at the base of the

Devonian. An unconformity at the top of the Mississippian sequence may indicate development of the Pedregosa Basin (**figure 1-4**). Another long hiatus in sedimentation ensued during latest Permian, Triassic, Jurassic, and possibly earliest Cretaceous time (although thin units of the Abo Formation and Naco Group are mapped in the Big Hatchet Mountains). This regional unconformity is recognized in southwestern New Mexico and southeastern Arizona.

Cretaceous and Tertiary units mapped in the Big Hatchet Mountains reflect Laramide and post-Laramide tectonic events. Deposits include the Glance Conglomerate (Bisbee Group) and the Hell-to-Finish, U-Bar, Mojado, and Rainvalley Formations. Tertiary andesitic and basaltic andesitic intrusives, conglomerate and sandstone, and rhyolitic ash-flow and air-fall tuffs, and rhyolitic intrusive breccias overlie the Mesozoic rocks. These units include the Little Hat Top Conglomerate and Bluff Creek Formation. Quaternary unconsolidated deposits unconformably overlie older units.

In the Big Hatchet Mountains, rocks are faulted by both high- and low-angle faults, including range-front faults, and have been folded—tightly near faults (**figure 4-2.1**). Folded rocks have been juxtaposed by subsequent thrust faults. Drewes (1991) separated the thrust-bounded plates into large northeast-directed plates and small southeast-directed backthrust plates. Both structural elements (folds and faults) typically trend northwest and are probably related to features of the Cordilleran orogeny, a named portion of the latest Laramide orogeny.

Deformation as described by Seager and Mack (1986) occurred in two stages: an initial stage of compressional deformation in Late Cretaceous or earliest Tertiary time (late Cordilleran orogenic events, or Laramide) that formed the Hidalgo Uplift and Ringbone Basin (to the north) and Little Hat Top Basin(?) to the south (**figure 1-5**). This was followed by an extensional stage in mid-Tertiary time (deformation) thought to be related to rifting in Rio Grande Valley area. This latter post-Laramide Basin-and-Range stage was accompanied by plutonism and volcanism. Local structures indicate that less regional deformational events also took place (Zeller, 1970). Quaternary deposits conceal many structures that flank the Big Hatchet Mountains and intermontane basins contain considerable thicknesses of Quaternary sediment.

Mineral Deposits

Big Hatchet mining district is in the Big Hatchet Mountains (see McLemore and Sutphin, this volume).

References

(* reference used in writing above summary)

*Deal, E.G., Elston, W.E., Erb, E.E., Peterson, S.L., Reiter, D.E., Damon, P.E., and Shafiqullah, M., 1978, Cenozoic volcanic geology of the Basin and Range province in

Hidalgo County, southwestern New Mexico, *in* Callender, J.F., Wilt, J.C., and Clemons, R.E., eds., Land of Cochise, Southeastern Arizona: New Mexico Geological Society, *in cooperation with* Arizona Geological Society, 29th Field Conference, p. 219-229.

*Drewes, Harald, 1991a, Geologic map of the Big Hatchet Mountains, Hidalgo County, New Mexico: U.S. Geological Survey Miscellaneous Investigations Series Map I-2144, scale 1:24,000.

*Drewes, Harald, Barton, H.N., Hanna, W.R., and Scott, D.C., 1988, Mineral resources of the Big Hatchet Mountains Wilderness Study Area, Hidalgo County, New Mexico: U.S. Geological Survey Bulletin 1735-C, 22 p.

*Elston, W.E., 1960, Reconnaissance geologic map of Virden 30' quadrangle: New Mexico Bureau of Mines and Mineral Resources Geologic Map 15, scale 1:126,720.

*Elston, W.E., 1965, Mining districts of Hidalgo County, New Mexico, *in* Fitzsimmons, J.P., and Lochman-Balk, Christina, eds., Guidebook of southwestern New Mexico II: New Mexico Geological Society Sixteenth Field Conference, p. 210-214.

Gramont, Bertrand, 1987, Carbonate sedimentology of the Virgilian part of the Horquilla Formation, Big Hatchet Peak area, Hidalgo County, New Mexico: Socorro, New Mexico Institute of Mining and Technology, unpublished M.S. thesis.

Gramont, B.P., and Johnson, D.B., 1986, Depositional environment of the upper Horquilla Formation (Permian not included) exposed in the west face of Big Hatchet Peak, Hidalgo County, New Mexico [abs.]: New Mexico Geology, v. 8, no. 3, p. 69.

Greenwood, E., Kottlowski, F.E., and Armstrong, A.K., 1970, Upper Paleozoic and Cretaceous stratigraphy of the Hidalgo County area, New Mexico, *in* Woodward, L.A., ed., Guidebook of the Tyrone-Big Hatchet Mountains-Florida Mountains Region: New Mexico Geological Society, 21st Annual Field Conference, p. 33-44.

*Griswold, G.B., 1961, Mineral deposits of Luna County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 72, 157 p.

Hopkins, R.T., 1988, Analytical results and sample locality maps of heavy–mineral–concentrate and rock samples from the Big Hatchet Mountains Wilderness Study Area (NM-030-035), Hidalgo County, New Mexico: U.S. Geological Survey [Microform].

*Kottlowski, F.E., 1962, Reconnaissance of commercial high-calcium limestones in New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 60, 77 p.

*Kottlowski, F.E., Foster, R.W., and Wengerd, S.A., 1969, Key oil tests and stratigraphic sections in southwest New Mexico, *in* Cordoba, D.A., Wengerd, S.A., and Shomaker, J., eds., Guidebook of the Border Region, Chihuahua and the United States: New Mexico

Geological Society, 20th Annual Field Conference, p. 186-196.

*Lindgren, W., Graton, L.C., and Gordon, C.H., 1910, The ore deposits of New Mexico: U.S. Geological Survey Professional Paper 68, 361 p.

*May, R.T., Smith, E.S., Dickson, R.E., and Nystrom, R.J., 1982, Douglas quadrangle, Arizona and New Mexico: Bendix Field Engineering Corporation, Grand Junction Operations, Report PGJ/F-118(82), 78 p.

*McLemore, V.T., 1983a, Uranium industry in New Mexico; history, production, and present status: New Mexico Geology, v. 5, no. 3, p. 45-51.

*McLemore, V.T., 1983b, Uranium and thorium occurrences in New Mexico--Distribution, geology, production, and resources, with selected bibliography: New Mexico Bureau of Mines and Mineral Resources Open File Report 183, 180 p.

*McLemore, V.T., and Lueth, V.W., 1995, Carbonate-hosted lead-zinc deposits in New Mexico: International Conference on Carbonate-Hosted Lead-Zinc Deposits [abs.]: Extended abstracts, Society of Economic Geologists, p. 209-211.

Million, D.T., 1986, Microfacies analysis and depositional environment comparison of two sections of Ordovician El Paso Formation, southern Franklin Mountains, west Texas, and northern Big Hatchet Mountains, southwest New Mexico [abs.]: New Mexico Geology, v. 8, no. 3, p. 68-69.

*Peterson, D.M., 1986, Enhanced conceptualization of Mesilla Bolson geohydrology through modelling studies [abs.]: New Mexico Geology, v. 8, no. 3, p. 70.

*Roswell Geological Society, 1958, Guidebook of the Hatchet Mountains and the Cooks Range - Florida Mountain areas, Grant, Hidalgo & Luna Counties, southwestern New-Mexico: 11th Field Conference, May 14, 15 and 16, 1958, 140 p.

Sandidge, Michael, 1982, Aptian-Albian ammonoids of the Oyster Limestone member of the U-Bar Formation, Big Hatchet Mountains, New Mexico [abs.]: New Mexico Geology, v. 4, no. 1, p. 13.

*Scott, D.C., 1986, Mineral resources of a part of the Big Hatchet Mountains Wilderness Study Area (NM-030-035), Hidalgo County, New Mexico: U.S. Bureau of Mines Mineral Land Assessment Open File Report 16-86, 31 p.

Scott, D.C., 1987a, Mineral investigation of additional parts of the Big Hatchet Mountains Wilderness Study Area (NM-030-035), Hidalgo County, New Mexico: U.S. Bureau of Mines Mineral Land Assessment Open File Report MLA 61-87, 9 p.

*Seager, W.R., and Mack, G.H., 1986b, Laramide paleotectonics of southern New Mexico, *in* Peterson, J.A., ed., Paleotectonics and Sedimentation in the Rocky Mountain Region,

United States: American Association of Petroleum Geologists Memoir 41, 669-685.

*Sivils, D.J., 1992, Preliminary stable isotope analysis of the Late Mississippian Paradise Formation, Big Hatchet Mountains, New Mexico [abs.]: New Mexico Geological Society Proceedings Volume, 1992 Annual Spring Meeting, p. 23.

*Strongin, Oscar, 1958, Geology and ore deposits of Apache Hills and northern Sierra Rica, Hidalgo County, New Mexico: New York, Columbia University, unpublished Ph. D. dissertation, 221 p.

Thompson, S., III, and Jacka, A.D., 1981, Pennsylvanian stratigraphy, petrography, and petroleum geology of Big Hatchet Peak section, Hidalgo County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 176.

U.S. Geological Survey, 1987, Aeromagnetic map of the Big Hatchet Mountains and vicinity, southwestern New Mexico: U.S. Geological Survey Open-File Report 87-0335.

*Weber, R.H., and Kottlowski, F.E., 1959, Gypsum resources of New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 68, 68 p.

Weise, J.R., 1982, Stratigraphy, lithofacies, and biofacies of the U-Bar Formation (Aptian-Albian) of the Big Hatchet Mountains, Hidalgo County, New Mexico: El Paso, University of Texas, unpublished Ph.D dissertation.

Weise, J.R., 1982b, Stratigraphy, petrography, and calcareous microfossils of the limestone-shale member, U-Bar Formation, Big Hatchet Mountains, Hidalgo County, New Mexico [abs.]: New Mexico Geology, v. 4, no. 1, p. 13.

*Woodward, L.A.,1970, ed., Guidebook of the Tyrone-Big Hatchet Mountains-Florida Mountains Region: New Mexico Geological Society, 21st Annual Field Conference, 162 p.

*Zeller, R.A., Jr., *with commentary by* Sam Thompson, III, 1975, Structural geology of Big Hatchet Peak Quadrangle, Hidalgo County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 146, 23 p., scale 1:48,000.

Zeller, R.A., Jr., 1958, The geology of the Big Hatchet Peak quadrangle, Hidalgo County, New Mexico: Los Angeles, University of California, Ph. D. dissertation, 260 p.

Zeller, R.A., Jr., 1960, Reef and associated facies of Horquilla Limestone, Big Hatchet Mountains area, southwestern New Mexico: Roswell Geological Society Guidebook, Northern Franklin Mountains and southern San Andres Mountains, p. 149-156.

Zeller, R.A., 1965, Stratigraphy of the Big Hatchet Mountains area, New Mexico: New Mexico Bureau of Mines and Mineral Resources Memoir 16, 128 p.

*Zeller, R.A., 1970, Geology of the Little Hatchet Mountains, Hidalgo and Grant Counties, New

Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 96, 23 p.
*Zeller, R.A., Jr., 1965, Stratigraphy of the Big Hatchet Mountains area, New Mexico: New Mexico Bureau of Mines and Mineral Resources Memoir 16, 128 p.

BROCKMAN HILLS

The Brockman Hills are located east of the Pyramid Mountains and north of the Little Hatchet Mountains and Coyote Hills.

General Geology

The ridges of the eastern and central part of the Brockman Hills are composed mainly of quartzite and shale of the Mojado Formation; these rocks were deformed during the Laramide orogeny into west-northwest-trending, overturned folds (**figure 4-2.2**). Folds verge to the north-northeast. Low rounded slopes of the westernmost Brockman Hills are composed of deeply weathered andesite of the Hidalgo Volcanics.

Exposures of the Horquilla Limestone and Mojado Formation that are thrust over Hidalgo andesite occur in the western Brockman Hills. Large horizontal displacement to the north-northeast on the exposed thrust fault is suggested by the shallow dip (7° SSW) of the fault. Estimated vertical separation along the thrust fault is estimated to be 7,625 m, and horizontal displacement to be several km to the northeast.

Shallow test wells encountered shale of the Ringbone Formation beneath Quaternary alluvium 1.5 km west and 6.5 km north of the Brockman Hills (not shown on map). About six kilometers north of Brockman Hills, a well penetrated nearly 1,830 m of Ringbone Formation overlying Ordovician carbonate rocks that had been intruded by rhyolite sills (R.W. Foster, 1974, personal commun., *in* Corbitt and others, 1977). The sill may mark a fault, or alternatively, an unconformity.

References

(* reference used in writing above summary)

*Corbitt, L.L., Nials, F.L., and Varnell, R.J., 1977, Structure of Brockman Hills, southwestern New Mexico: American Association of Petroleum Geologists Bulletin, v. 61, no. 4, p. 601-607.
*Drewes, H., 1991, Geologic map of the Big Hatchet Mountains, Hidalgo County, New Mexico: U.S. Geological Survey Miscellaneous Investigations Series Map I-2144, scale 1:24,000.
*Thorman, C.H., 1977, Geologic map of the Coyote Peak and Brockman quadrangles, Hidalgo and Grant Counties, New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map MF-924, scale 1:24,000.

LITTLE HATCHET MOUNTAINS

The Little Hatchet Mountains, Hidalgo and Grant Counties, are a northwest-trending fault-block north of the Big Hatchet Mountains.

General Geology

From base to top, the exposed stratigraphic succession of bedded rocks in the Little Hatchet Mountains consists of undifferentiated Precambrian intrusive rocks, Bliss Formation, Horquilla Limestone, Earp Formation(?), unnamed limestone, dolomite, gypsum, and shale units (probably Early Cretaceous in age; as much as 458 m thick), Hell-to-Finish Formation, U-Bar Formation, Mojado Formation, Ringbone Formation, Magdalena Group, unnamed Upper Cretaceous or Lower Tertiary intrusive and silicified sedimentary rocks and Bisbee Group rocks (including Hidalgo Volcanics, Howells Ridge formation, Morita Formation, and Playas Peak formation), unnamed volcanic rocks, and Quaternary alluvium and pediment deposits (Zeller, 1970). Unconformities exist between the Mojado and Ringbone Formations, between the Ringbone Formation and Hidalgo Volcanics, between Late Tertiary rocks and Tertiary volcanic rocks, and between the Hidalgo Volcanics and Late Tertiary deposits. Cretaceous sequences make up the majority of exposed rocks in the range. Volcanic rocks are rhyolitic and latitic pyroclastic rocks with interbedded sandstone and clay. Sedimentary rocks contain interbedded basaltic lava flows and pyroclastic deposits, and one small intrusive composed of orthoclase gabbro (possibly an intrusive equivalent of the basaltic extrusive deposits).

Intrusive rocks include stocks, dikes, and sills that are related to mineralization locally. The oldest rocks are in the southern part of the range and in isolated hills where Precambrian porphyritic granite has been cut by northeast-trending aplite dikes (Lasky, 1947; Zeller, 1970). Sills and stocks intrude Cretaceous volcanic and sedimentary units in three locations (Old Hachita, Sylvanite, and Granite Pass) and are associated with contact-metamorphic haloes containing ore deposits.

Igneous rocks include diorite sills, gabbro, monzonite, quartz monzonite, and granite stocks, porphyry, lamprophyre, and aplite dikes, latite and felsite dikes and sills, pods of granite along the Copper Dick fault (an east–trending fault that bisects the range), and Pleistocene basalt. The youngest dated intrusive rock is the granite at Granite Pass, shown to be 43-48 Ma (zircon, fission track; Zeller, 1970). Rhyolite, felsite, and latite dikes intrude this granite as well as older intrusive rocks. The degree of metamorphism surrounding the intrusives is related to distance from the intrusions; rocks in the northern part of the range are unmetamorphosed.

Three broad, northwest-trending faulted folds are Vista anticline in the northern, Howells Wells syncline in the central, and an unnamed monocline in the southern parts of the Little Hatchet

Mountains. Major normal and thrust faults include the Hatchet Gap, Miss Pickle, and National faults in the northern part of the range, and the Copper Dick and Howells Wells faults in the central part of the range. Range–bounding faults on the southeastern side of the Little Hatchet Mountains have been determined by seismic profiles (subsurface evidence) to be listric (curving, concave-upward) normal faults and associated antithetic faults (opposite offset to that of the normal fault)(Chang and others, 1994). These faults apparently dip at a high angle near the surface, but become shallowly dipping at depth (Chang and others, 1994). Faulting occurred from pre-intrusion to post-Miocene tectonic phases.

Mineral Deposits

Sylvanite mining district is in the Little Hatchet Mountains. Massive white marbleized limestone on the west side of Granite Pass is identified as Horquilla Limestone by Zeller (1970). Eureka mining district occurs in the northern part of the Little Hatchet Mountains in Grant County.

References

(* reference used in writing above summary)

*Anderson, E.C., 1957, The metal resources of New Mexico and their economic features through 1954: New Mexico Bureau of Mines and Mineral Resources Bulletin 39, 183 p.

Basabilvazo, G.T., 1991, Stratigraphy, depositional environments, and sediment dispersal pathways of the Upper Cretaceous Ringbone Formation in the Little Hatchet Mountains of southwestern New Mexico: Las Cruces, New Mexico State University, unpublished Master's thesis, 157 p.

*Chang, J., Miller, K.C., Thompson III, S., and Keller, G.R., 1994, Relationship of Laramide and Basin and Range structures in the Pedregosa Basin, southwestern New Mexico, *in* Geologic activities in the 90s, Southwest Section of AAPG 1994, Ruidoso, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 150, p. 128-129.

*Dale, V.B., and McKinney, W.A., 1959, Tungsten deposits of New Mexico: U.S. Bureau of Mines Report of Investigations 5517, 72 p.

*Dinsmore, C.A., 1908, The new gold camp of Sylvanite, New Mexico: Mining World, v. 29, p. 670-671.

*Elston, W.E., 1965a, Mining districts of Hidalgo County, New Mexico, *in* Fitzsimmons, J.P., and Lochman-Balk, Christina, eds., Guidebook of southwestern New Mexico II: New Mexico Geological Society, 16th Field Conference, p. 210-214.

Greenwood, E., Kottlowski, F.E., and Armstrong, A.K., 1970, Upper Paleozoic and Cretaceous stratigraphy of the Hidalgo County area, New Mexico, *in* Woodward, L.A., ed.,

Guidebook of the Tyrone-Big Hatchet Mountains-Florida Mountains Region: New Mexico Geological Society, 21st Annual Field Conference, p. 33-43.

*Hammarstrom, J.M., Drewes, Harald, Friedman, J.D., Klein, D.P., Kulik, D.M., Watts, K.C., Jr., Pitkin, J.A., Simpson, S.L., and Theodore, T.G., 1988, Preliminary mineral resource assessment of the Douglas 1° x 2° quadrangle, Arizona-New Mexico: U.S. Geological Survey Administrative Report, 228 p., including indices.

*Johnson, M.G., 1972, Placer gold deposits of New Mexico: U.S. Geological Survey Bulletin 1348, 46 p.

*Jones, F.A., 1908a, Sylvanite, New Mexico--The new gold camp: Engineering and Mining Journal, v. 86, p. 1101-1103.

Jones, F.A., 1908b, The new camp of Sylvanite, New Mexico: Mining Science, v. 58, p. 489-490.

*Lasky, S.G., 1938b, Outlook for further ore discoveries in the Little Hatchet Mountains, New Mexico: Economic Geology, v. 38, p. 365-389.

*Lasky, S.G., 1947, Geology and ore deposits of the Little Hatchet Mountains, Hidalgo and Grant Counties, New Mexico: U.S. Geological Survey Professional Paper 208, 101 p.

*Lawton, T.F., Basbilvazo, G.T., Hodgson, S.A., Wilson, D.A., Mack, G.H., McIntosh, W.C., Lucas, S.G., and Kietzke, K.K., 1993, Laramide stratigraphy of the Little Hatchet Mountains, southwestern New Mexico: New Mexico Geology, v. 15, no. 1, p. 9-15.

*Lindgren, W., Graton, L.C., and Gordon, C.H., 1910, The ore deposits of New Mexico: U.S. Geological Survey Professional Paper 68, 361 p.

Loring, A.K., and Loring, R.B., 1980, Age of thrust faulting, Little Hatchet Mountains, southwestern New Mexico: Isochron/West, no. 27, p. 29-30.

*Martin, G.A., 1908, Sylvanite, New Mexico: Engineering and Mining Journal, v. 86, no. 12, p. 962-963.

*McLemore, V.T., 1994b, Placer gold deposits in New Mexico: New Mexico Geology, v. 16, p. 21-25.

Wilson, D.A., 1991, Depositional environments, provenance, and age of the Skunk Ranch Formation, Little Hatchet Mountains, southwestern New Mexico: Las Cruces, New Mexico State University, unpublished Master's thesis, 70 p.

Zeller, R.A., 1959, Reconnaissance geologic map of Playas 15' quadrangle: New Mexico Bureau of Mines and Mineral Resources Geologic Map 75, scale 1:62,500.

*Zeller, R.A., 1970, Geology of Little Hatchet Mountains, Hidalgo and Grant Counties, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 96, 23 p.

Zeller, R.A., Jr., and Alper, A.M., 1965, Geology of the Walnut Wells quadrangle, Hidalgo County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 84, 105 p., scale 1:48,000.

PELONCILLO MOUNTAINS

The Peloncillo Mountains are located along the New Mexico-Arizona state line, western Hidalgo County.

General Geology

The Peloncillo Mountains are composed of Middle Tertiary volcanic rocks (Granite Gap Granite) resting unconformably on Precambrian, Paleozoic, and Mesozoic rocks, and cut by middle Tertiary or younger normal and thrust faults. The sequence has been folded into a northwest-trending arch and faulted by high-angle, northwest-trending, normal faults along the axis of the arch. Northwest-trending normal faults and several major northeast-trending normal faults that postdate them, control location of subsequent intrusives.

Paleozoic rocks include the Bliss Formation, El Paso Limestone, Montoya Group, Percha Shale, Escabrosa Limestone (Hachita and Keating Formations), Paradise Formation, Naco Group (Horquilla Limestone, Earp Formation, Colina Limestone, Scherrer Formation, and Concha Limestone), separated from the overlying Early Cretaceous (Bisbee Group, Hell-to-Finish, Morita, U-Bar, and Mojado Formations) rocks by an unconformity.

Precambrian granite and Paleozoic strata are intruded and metamorphosed by igneous rocks that are older than overlying (Tertiary?) volcanic sequences, but dikes and sills related to the volcanic sequences cut the layered sediments. Elston (1983, 1984) tentatively describes the existence of Rodeo caldera by the occurrence of extensive megabreccia deposits (Antelope Pass unit). The Geronimo Trail caldera, filled with the tuff of Guadalupe Canyon and the breccia of Hog Canyon, has been described as a resurgent caldera (Erb, 1979). Moat deposits and ring fracture domes that become more siliceous with time are composed of the dacite of Outlaw Mountain, volcanics of Hog Ranch, quartz latite of Hickory Creek, rhyolite of Clanton Draw, and several unnamed volcaniclastic units (Erb, 1979). The Gillespie Tuff occurs in the southern Peloncillo Mountains.

Mineral Deposits

Granite Gap (San Simon), Kimball (Steins Pass), McGhee Peak, and Silvertip mining districts are in the Peloncillo Mountains. Metamorphism associated with Late Cretaceous to middle Tertiary intrusive activity is pervasive and includes alteration (propylitization) of igneous rocks, formation of skarn zones along contacts with igneous intrusives, and metamorphism (hornfelsification and recrystallization) of clastic rocks.

According to Kottlowski (1962), high-calcium limestone may occur in the Escabrosa Limestone, Horquilla Limestone, Colina Limestone, and Bisbee Group limestones, although they may contain impurities such as chert. Their extent is not known.

References

(* reference used in writing above summary)

*Anderson, E.C., 1957, The metal resources of New Mexico and their economic features through 1954: New Mexico Bureau of Mines and Mineral Resources Bulletin 39, 183 p.

Armin, R.A., 1987, Sedimentology and tectonic significance of Wolfcampian (Lower Permian) conglomerates in the Pedregosa Basin; southeastern Arizona, southwestern New Mexico, and northern Mexico: Geological Society of America Bulletin, v. 99, no. 1, p. 42-65.

Armstrong, A.K., 1962, Stratigraphy and paleontology of the Mississippian System in southwestern New Mexico and adjacent southeastern Arizona: New Mexico Bureau of Mines and Mineral Resources Memoir 8, 99 p.

Armstrong, A.K., and Mamet, B.L., 1978, The Mississippian System of southwestern New Mexico and southeastern Arizona, *in* Callender, J.F., Wilt, J.C., and Clemons, R.E., eds., Land of Cochise, Southeastern Arizona: New Mexico Geological Society, *in cooperation with* Arizona Geological Society, 29th Annual Field Conference, p. 183-192.

Armstrong, A.K., and Mamet, B.L., 1988, Mississippian (Lower Carboniferous) biostratigraphy, facies, and microfossils, Pedregosa Basin, southeastern Arizona and southwestern New Mexico: U.S. Geological Survey Bulletin 1826, 40 p.

Armstrong, A.K., and Silberman, M.L., 1974, Geologic map of the central Peloncillo Mountains, Hidalgo County, New Mexico: U.S. Geological Survey Open-File Report 74-11.

*Armstrong, A.K., Silberman, M.L., Todd, V.R., Hoggatt, W.C., and Carton, R.B., 1978, Geology of the central Peloncillo Mountains, Hidalgo County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 158, 18 p.

Bahlburg, W.C., 1977, Depositional environments of the Tamaroa Sequence (Mississippian) of southeastern Arizona, southwestern New Mexico, and northern Mexico: Arizona State University, unpublished Master's thesis.

Calder, S.R., 1982, The geology of, and known mineral occurrences within, Wilderness Study Area 4-60, Vanar Hills-Peloncillo Mountains: Arizona Bureau of Geology and Mineral Technology Open-file Report 83-6, 18 p.

*Cargo, D.N., 1959 Mineral deposits of the Granite Gap area, Hidalgo County, New Mexico: University of New Mexico, unpublished Master's thesis, 70 p.

Carten, R.B., Silberman, M.L., and Armstrong, A.K., 1974, Geology, trace-metal anomalies and

base-metal mineralization in the central Peloncillo Mountains, Hidalgo County, New Mexico [abs.]: New Mexico Institute of Mining and Technology, Symposium on base metal and fluorspar districts of New Mexico, p. 7.

*Dale, V.B., and McKinney, W.A., 1959, Tungsten deposits of New Mexico: U.S. Bureau of Mines Report of Investigations 5517, 72 p.

*Deal, E.G., Elston, W.E., Erb, E.E., Peterson, S.L., Reiter, D.E., Damon, P.E., and Shafiqullah, M., 1978, Cenozoic volcanic geology of the Basin and Range province in Hidalgo County, southwestern New Mexico, *in* Callender, J.F., Wilt, J.C., and Clemons, R.E., eds., Land of Cochise, Southeastern Arizona: New Mexico Geological Society, *in cooperation with* Arizona Geological Society, 29th Field Conference, p. 219-229.

*Drewes, Harald, and Thorman, C.H., 1980, Geologic map of the Cotton City Quadrangle and the adjacent part of the Vanar Quadrangle, Hidalgo County, New Mexico: U.S. Geological Survey Miscellaneous Investigations Series Map I-1221, scale 1:24,000.

Elston, W.E., 1959, Some features of pyrometasomatic ore deposits in the Peloncillo Mountains, Hidalgo County, New Mexico: New Mexico Geological Society Guidebook, 10th Field Conference, p. 159-160.

*Elston, W.E., 1960, Reconnaissance geologic map of Virden 30' quadrangle: New Mexico Bureau of Mines and Mineral Resources Geologic Map 15, scale 1:126,720.

*Elston, W.E., 1983, Cenozoic volcanic centers in the New Mexico segment of the Pedregosa Basin; constraints on oil and gas exploration in southwestern New Mexico--Application of volcanology to petroleum exploration in southwestern New Mexico: Albuquerque, University of New Mexico report NMERDI 2-66-3104, 54 p.

*Elston, W.E., 1984a, Mid-Tertiary ash flow tuff cauldrons, southwestern New Mexico: Journal of Geophysical Research, v. 89, no. 10, p. 8733-8750.

*Enders, M.S., 1981, The geology, mineralization, and exploration characteristics of the Beck mine and vicinity, Kimball mining district, Hidalgo County, New Mexico and Cochise County, Arizona: Tucson, University of Arizona Master's thesis, 109 p.

*Emanuel, K.M., 1985, Geronimo project report: Nicor Mineral Ventures, Inc., unpublished report on file at NMBMMR, January 18, 1985, 30 p.

Erb, E.E., 1979, Petrologic and structural evolution of ash-flow tuff cauldrons and noncauldron related volcanic rocks in the Animas and southern Peloncillo Mountains, Hidalgo Co., New Mexico: Albuquerque, University of New Mexico, Ph. D. dissertation, 286 p.

*Farnham, L.L., 1961, Manganese deposits of New Mexico: U.S. Bureau of Mines Information Circular 8030, 176 p.

*Gebben, D.J., 1978, Geology of the central Peloncillo Mountains, the north third of the Pratt quadrangle, Hidalgo County, New Mexico: Kalamazoo,Western Michigan University, Master's thesis, 126 p.

Gillerman, Elliot, 1958, Geology of the central Peloncillo Mountains, Hidalgo County, New Mexico and Cochise County, Arizona: New Mexico Bureau of Mines and Mineral Resources Bulletin 57, 152 p.

*Goodspeed, Thomas, and Lucas, S.G., 1992, Early Cretaceous (Aptian) ammonites from the central Peloncillo Mountains, southwestern New Mexico [abs.]: New Mexico Geological Society Proceedings Volume, 1992 Annual Spring Meeting, p. 36.

Hayes, P.T., 1970, Cretaceous paleogeography of southeastern Arizona and adjacent areas: U.S. Geological Survey Professional Paper 658-B, 42 p.

*Hayes, P.T., 1982, Geologic map of Bunk Robinson Peak and Whitmire Canyon Roadless Areas, Coronado National Forest, New Mexico, and Cochise County, Arizona: U.S. Geological Survey Miscellaneous Field Studies Map MF-1425-A, 5 p.

Hayes, P.T., assisted by Cone, G.C., 1975, Cambrian and Ordovician rocks of southern Arizona and New Mexico and westernmost Texas: U.S. Geological Survey Professional Paper 873, 98 p.

*Hayes, P.T., and Brown, S.D., 1984, Bunk Robinson Peak and Whitmire Canyon Roadless Areas, New Mexico and Arizona, *in* Marsh, S.P., Kropschot, S.J., and Dickinson, R.G., ed., Wilderness mineral potential; assessment of mineral-resource potential in U.S. Forest Service lands studied 1964-1984: U.S. Geological Survey Professional Paper 1300, p. 799-800.

*Hayes, P.T., Watts, K.C., Hassemer, J.R., and Brown, S.D., 1983, Mineral resource potential of Bunk Robinson Peak and Whitmire Canyon Roadless Areas, Hidalgo County, New Mexico, and Cochise County, Arizona: U.S. Geological Survey Miscellaneous Field Studies Map MF-1425-B, scale 1:62,500.

Hoggatt, W.C., Silberman, M.L., and Todd, V.R., 1977, K-Ar ages of intrusive rocks of the central Peloncillo Mountains, Hidalgo County, New Mexico: Isochron West, no. 19, p. 3-6.

Hudson, J.S., 1984, Geology and hydrothermal alteration of the San Simon mining district south of Steins Pass, Peloncillo Mountains, Hidalgo County, New Mexico: Albuquerque, University of New Mexico, unpublished Master's thesis, 125 p.

*Kottlowski, F.E., 1962, Reconnaissance of commercial high-calcium limestones in New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 60, 77p.

Kottlowski, F.E., Foster, R.W., and Wengerd, S.A., 1969, Key oil tests and stratigraphic sections in southwest New Mexico, *in* Cordoba, D.A., Wengerd, S.A., and Shomaker, J., eds., Guidebook of the Border Region; Chihuahua and the United States: New Mexico Geological Society, 20th Annual Field Conference, p. 186-196.

*Lasky, S.G., and Wootton, T.P., 1933, The metal resources of New Mexico and their economic features: New Mexico Bureau of Mines and Mineral Resources Bulletin 7, 178 p.

*Lindgren, W., Graton, L.C., and Gordon, C.H., 1910, The ore deposits of New Mexico: U.S. Geological Survey Professional Paper 68, 361 p.

McIntyre, D.H., 1988, Volcanic geology in parts of the southern Peloncillo Mountains, Arizona and New Mexico: U.S. Geological Survey Bulletin 1671, 18 p.

*McLemore, V.T., and Lueth, V.W., 1995, Carbonate-hosted lead-zinc deposits in New Mexico: International Conference on Carbonate-Hosted Lead-Zinc Deposits [abs.]: Extended abstracts, Society of Economic Geologists, p. 209-211.

*McLemore, V.T., McIntosh, W.C., and Pease, T.C., 1995, $^{40}Ar/^{39}Ar$ age determinations of four plutons associated with mineral deposits in southwestern New Mexico: New Mexico Bureau of Mines and Mineral Resources Open File Report 410.

Quaide, W.L., 1953, Geology of the central Peloncillo Mountains, Hidalgo County, New Mexico: Berkeley, University of California, unpublished Master's thesis, 87 p.

*Richter, D.H., and Lawrence, V.A., 1983, Mineral deposit map of the Silver City 1° x 2° quadrangle, New Mexico and Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map I-1310-B, 70 p., scale 1:250,000.

*Richter, D.H., Lawrence, V.A., Drewes, Harald, Young, T.H., Enders, M.S., Damon, P.E., and Thorman, C.H., 1990, Geologic map of the San Simon quadrangle and parts of the Summit Hills and Mondel Quadrangles, Cochise, Graham, and Greenlee Counties, Arizona, and Hidalgo County, New Mexico: U.S. Geological Survey Miscellaneous Investigations Series Map I-1951, scale 1:48,000.

Sandidge, Michael, 1983, Preliminary report on Carbonate Hill Limestone (Aptian) of central Peloncillo Mountains, Hidalgo County, New Mexico [abs.]: New Mexico Geology, v. 5, no. 3, p. 65.

Sivils, D.J., and Johnson, D.B., 1993, Stratigraphy and sedimentation of the Paradise Formation (Late Mississippian) in the Peloncillo Mountains, Hidalgo County, New Mexico: Proceedings volume, 1993 Annual Spring Meeting, New Mexico Geological Society, Socorro, p. 6.

Todd, V.R., Silberman, M.L., and Armstrong, A.K., 1975, Geochemistry, petrology, and K-Ar

ages of igneous rocks in the central Peloncillo Mountains, Hidalgo County, New Mexico [abs.]: New Mexico Geological Society and Arizona Geological Society, Symposium on base-metal and precious-metal districts of New Mexico and Arizona, p. 25-26.

*Watts, K.C., Hassemer, J.R., and Day, G.W., 1983, Geochemical maps of Bunk Robinson Peak and Whitmire Canyon Roadless Areas, Hidalgo County, New Mexico, and Cochise County, Arizona: U.S. Geological Survey Miscellaneous Field Studies Map MF-1425-C, scale 1: 62,500.

*Wells, E.H., and Wootton, T.P., 1932, *revised by* Wootton, T.P., Gold mining and gold deposits in New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 5, 24 p.

*Wells, E.H., and Wootton, T.P, 1940, Gold mining and gold deposits in New Mexico (revised ed.): New Mexico Bureau of Mines and Mineral Resources Circular 5, 25 p.

*Williams, S.A., 1978, Mineralization at Granite Gap, Hidalgo County, New Mexico, *in* Callender, J.F., Wilt, J.C., and Clemons, R.E., eds., Land of Cochise, Southeastern Arizona: New Mexico Geological Society, *in cooperation with* Arizona Geological Society, 29th Annual Field Conference, p. 329-330.

*Wrucke, C.T., and Bromfield, C.S., 1961, Reconnaissance geologic map of part of the southern Peloncillo Mountains, Hidalgo County, New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map MF-160.

*Young, T.H., 1982, Geological and exploration characteristics of precious-metal mineralization at the Volcano mine and vicinity, Peloncillo Mountains, Hidalgo County, New Mexico: Tucson, University of Arizona, unpublished Ph. D. dissertation.

PLAYAS VALLEY

General Geology

Playas Valley, bordered on the west by the Animas Mountains and on the east by the Little Hatchet Mountains, contains ancient Playas Lake and thick Quaternary deposits. Boulder and cobble conglomerate and sandstone alluvial fans, composed entirely of Tertiary volcanic detritus, are deposited on the eastern slopes of the northern Animas Mountains and trend into Playas Valley. As much as 732 m of Gila Conglomerate has been reported to occur in the subsurface (Thompson and others, 1978).

Seismic reflection and gravity profiles within Playas and Hachita Valleys indicate that Precambrian basement exists at depth and is involved in northeast-verging Laramide thrust faulting (Klein, this volume; Chang and others 1994).

References

(* reference used in writing above summary)

*Chang, J., Miller, K.C., Thompson III, S., and Keller, G.R., 1994, Relationship of Laramide and Basin and Range structures in the Pedregosa Basin, southwestern New Mexico, *in* Geologic activities in the 90s, Southwest Section of AAPG 1994, Ruidoso, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 150, p. 128-129.

Doty, G.C., 1960, Reconnaissance of ground water in Playas Valley, Hidalgo County, New Mexico: Santa Fe, State of New Mexico, *prepared in cooperation with* the U.S. Geological Survey.

*Hawley, J.W., and Kottlowski, 1965, Road log from Lordsburg to San Simon Valley, *in* Fitzsimmons, J.P., and Lochman-Balk, Christina, eds., Guidebook of southwestern New Mexico II: New Mexico Geological Society, 16th Field Conference, p. 76-81.

Schwennesen, A.T., 1918, Ground water in the Animas, Playas, Hachita, and San Luis basins, Arizona and New Mexico: U.S. Geological Survey Water-Supply Paper 422, 152 p.

*Thompson, S., III, Tovar, R.J.C., and Conley, J.N., 1978, Oil and gas exploration wells in the Pedregosa Basin, *in* Callender, J.F., Wilt, J.C., and Clemons, R.E., eds., Land of Cochise, Southeastern Arizona: New Mexico Geological Society, *in cooperation with* Arizona Geological Society, 29th Field Conference, p. 331-342.

Zeller, R.A., 1958, Reconnaissance geologic map of Playas 15' quadrangle: New Mexico Bureau of Mines and Mineral Resources Geologic Map 7, scale 1:62,500.

PYRAMID MOUNTAINS

The Pyramid Mountains are located in the north-central part of Hidalgo County.

General Geology

In a series of low hills southwest of the deeply eroded Pyramid Mountains, Paleozoic rocks, which were deposited in a carbonate shelf environment, crop out. Pre-Muir caldera rocks in the Pyramid Mountains are of Pennsylvanian and Cretaceous age (probably Horquilla Limestone, U-Bar, and Mojado Formations), Late Cretaceous to early Tertiary (Laramide) intrusive and extrusive rocks (basalt and andesite), and Oligocene andesite. Most volcanic rocks of the Pyramid Mountains have calc-alkalic associations (many rhyolite ash-flow tuffs, lava flows, and breccias)(Deal and others, 1978; Elston and others, 1983; Elston, 1994).

Muir Caldera

In most of the Pyramid Mountains, middle Tertiary rocks and geologic structures are dominated by the Muir caldera (Deal and others, 1978; Elston and others, 1983; Elston, 1994). The 20-km diameter caldera is an elongate structure, the long axis striking northwest roughly parallel to the pre-Tertiary basement structures in the region. Muir complex formed in two stages separated by an interval of caldera collapse. The inner caldera contains a thick fill of ash-flow tuff and, is bordered by a collapsed caldera wall and three zones of successive ring-fracture felsic domes, flows, and moat deposits outside of the caldera wall. The caldera collapsed in two stages, each associated with a rhyolite ash-flow tuff sheet and ring-fracture domes. Ring-fracture zones and the caldera wall are preserved only on part of the northeast side. The remainder of the zones are hidden beneath Animas and Playas Valleys.

Pre-caldera rocks consist of Pennsylvanian and Cretaceous sedimentary rocks, late Cretaceous and/or early Tertiary basalt and andesite, and Oligocene andesite (Elston and others, 1983). The initial stage of rhyolitic lavas and tuffs (rhyolite of José Placencia Canyon) culminated in the eruption of the Woodhaul Canyon rhyolite ash-flow tuff. Caldera collapse took place during eruption of the second eruptive stage, and resulted in formation of a megabreccia and associated hydrothermal alteration. The second stage of eruption began with the tuff of Graham Well, which is surrounded by two belts of flows and domes. The inner belt is composed of the rhyolite of Pyramid Peak and associated tuffs, and the outer belt is composed of the latite of Uhl Well. Both of these deposits are interpreted as moat and flank deposits along the ring fracture domes of Muir caldera.

Details of the geometry and structure of Muir caldera and the succession of events that formed it are given in Elston and others (1983). Age of the caldera (36-37 Ma, early Oligocene; Deal and others, 1978) makes it one of the oldest known calderas in New Mexico.

Post-Caldera Rocks

A later group of Oligocene-early Miocene post-caldera ash-flow tuffs and basaltic flows is designated the Rimrock Mountain Group of Elston and others (1979). The group is composed of rhyolite or quartz-latite ash-flow tuff units interlayered with basaltic andesite flow units, sandstone, and conglomerate beds. These tuffs originated beyond the Pyramid Mountains—some from the Animas Mountains to the south and some from unknown sources. Numerous diorite, monzonite porphyry, andesite, and rhyolite dikes and small stocks [one dated at 29 Ma (whole rock, K-Ar; Elston and others, 1983)] intrude the caldera and older rocks (Elston and others, 1983).

An intrusive stock north of Lightning Dock Mountain and associated dikes that radiate from the stock apparently pre-date the Rimrock Mountain Group of Elston and others, (1979) and

younger rocks. The youngest rock unit intruded by the stock is the tuff of Woodhaul Canyon.

Mineral Deposits

Lordsburg and Muir mining districts are in the Pyramid Mountains.

References

(* reference used in writing above summary)

*Agezo, F.L., and Norman, D.I., 1993, Mineralogy, alteration, and fluid inclusion study of the Lordsburg Mining District, Hidalgo County, New Mexico: Socorro, New Mexico Geological Society Spring Meeting, Proceedings, p. 28.

*Agezo, F.L., and Norman, D.I., 1994, Mineralogy, alteration, and fluid inclusion study of the Lordsburg Mining District, Hidalgo County, New Mexico: Society for MIning, Metallurgy, and Exploration, Inc., 1994 Annual Meeting and Exhibit, Program with Abstracts, p. 116.

Clark, K.F., 1962, Hypogene zoning in the Lordsburg mining district, Hidalgo County, New Mexico: University of New Mexico, unpublished Master's thesis, 136 p.

Clark, K.F., 1962, Hypogene zoning in the Lordsburg mining district, Hidalgo County, New Mexico [abs.], *in* Ash, S.R., and Davis, L.V., eds., Ruidoso Country (New Mexico): New Mexico Geological Society, 15th Annual Field Conference, p. 186-187.

Clark, K.F., 1970, Zoning, paragenesis, and temperatures of formation in the Lordsburg district, *in* Woodward, L.A., ed., Copper, gold, and silver ores, New Mexico: Guidebook of the Tyrone-Big Hatchet Mountains-Florida Mountains region; New Mexico Geological Society, p. 107-113.

*Deal, E.G., Elston, W.E., Erb, E.E., Peterson, S.L., Reiter, D.E., Damon, P.E., and Shafiqullah, M., 1978, Cenozoic volcanic geology of the Basin and Range province in Hidalgo County, southwestern New Mexico, *in* Callender, J.F., Wilt, J.C., and Clemons, R.E., eds., Land of Cochise, Southeastern Arizona: New Mexico Geological Society, *in cooperation with* Arizona Geological Society, 29th Field Conference, p. 219-229.

*Elston, W.E., 1965, Mining districts of Hidalgo County, New Mexico, *in* Fitzsimmons, J.P., and Lochman-Balk, Christina, eds., Guidebook of southwestern New Mexico II: New Mexico Geological Society, 16th Field Conference, p. 210-214.

*Elston, W.E., 1983, Cenozoic volcanic centers in the New Mexico segment of the Pedregosa Basin; constraints on oil and gas exploration in southwestern New Mexico--Application of volcanology to petroleum exploration in southwestern New Mexico: Albuquerque, University of New Mexico report NMERDI 2-66-3104, 54 p.

*Elston, W.E., 1994, Siliceous volcanic centers as guides to mineral exploration --review and

summary: Economic Geology, v. 89, no. 8, p. 1662-1686.

*Elston, W.E., Deal, E.G., and Logsdon, M.J., 1983, Geology and geothermal waters of Lightning Dock region, Animas Valley and Pyramid Mountains, Hidalgo County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 177, 44 p., map scale 1:48,000.

*Elston, W.E., Erb, E.E., and Deal, E.G., 1979, Tertiary geology of Hidalgo County, New Mexico; guide to metals, industrial minerals, petroleum, and geothermal resources: New Mexico Geology, v. 1, no. 1, p. 1-6.

*Flege, R.F., Jr., 1959, Geology of Lordsburg quadrangle, Hidalgo County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 62, 36 p. [Also Master's thesis, St. Louis, MO, Washington University, 1956].

*Hill, G.T., 1994, Geochemistry of southwestern New Mexico fluorite deposits with possible base and precious metals exploration significance: Socorro, New Mexico Institute of Mining and Technology, M.S. thesis, 44 p.

*Huntington, M.G., 1947, Atwood copper group, Lordsburg district, Hidalgo County, New Mexico: U.S. Bureau of Mines Report of Investigations 4029, 9 p.

*Johnson, M.G., 1972, Placer gold deposits of New Mexico: U.S. Geological Survey Bulletin 1348, 46 p.

*Jones, F.A., 1907, The Lordsburg mining region, New Mexico: Engineering and Mining Journal, v. 84, p. 444-445.

*Lasky, S.G., 1936a, Hydrothermal leaching in the Virginia mining district, New Mexico: Economic Geology, v. 31, p. 156-169.

*Lasky, S.G., 1938a, Geology and ore deposits of the Lordsburg mining district, Hidalgo County, New Mexico: U.S. Geological Survey Bulletin 885, 62 p.

*Marvin, R.F., Mehnert, H.H., and Naeser, C.W., 1988, U.S. Geological Survey radiometric ages—compilation "C", Pt. 2; Arizona and New Mexico: Isochron/West, no. 51, p. 5-13.

*McAnulty, W.N., 1978, Fluorspar in New Mexico: New Mexico Bureau of Mines and Mineral Resources Memoir 34, 64 p.

*McLemore, V.T., 1994b, Placer gold deposits in New Mexico: New Mexico Geology, v. 16, p. 21-25.

*McLemore, V.T., McIntosh, W.C., and Pease, T.C., 1995, $^{40}Ar/^{39}Ar$ age determinations of four plutons associated with mineral deposits in southwestern New Mexico: New Mexico Bureau of Mines and Mineral Resources Open File Report 410.

*Raines, G.L., Erdman, J.A., McCarthy, J.H., and Reimer, G.M., 1985, Remotely sensed

limonite anomaly on Lordsburg Mesa, New Mexico--Possible implications for uranium deposits: Economic Geology and the Bulletin of the Society of Economic Geologists, v. 80, no. 3, p. 575-590.

*Richter, D.H., and Lawrence, V.A., 1983, Mineral deposit map of the Silver City 1°x2° quadrangle, New Mexico and Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map I-1310-B, 70 p., scale 1:250,000.

*Richter, D.H., Lawrence, V.A., Drewes, Harald, Young, T.H., Enders, M.S., Damon, P.E., and Thorman, C.H., 1990, Geologic map of the San Simon quadrangle and parts of the Summit Hills and Mondel Quadrangles, Cochise, Graham, and Greenlee Counties, Arizona, and Hidalgo County, New Mexico: U.S. Geological Survey Miscellaneous Investigations Series Map I-1951, scale 1:48,000.

Thorman, C.H., and Drewes, Harald, 1978a, Cretaceous-early Tertiary history of the northern Pyramid Mountains, southwestern New Mexico, *in* Callender, J.F., Wilt, J.C., and Clemons, R.E., eds., Land of Cochise, Southeastern Arizona: New Mexico Geological Society, *in cooperation with* Arizona Geological Society, 29th Field Conference, p. 215-218.

*Thorman, C.H., and Drewes, Harald, 1978b, Geologic map of the Gary and Lordsburg quadrangles, Hidalgo County, New Mexico: U.S. Geological Survey Miscellaneous Investigations Series Map I-1151, scale 1:24,000.

*Watts, K.C., Hassemer, J.R., and Day, G.W., 1983, Geochemical maps of Bunk Robinson Peak and Whitmire Canyon Roadless Areas, Hidalgo County, New Mexico, and Cochise County, Arizona: U.S. Geological Survey Miscellaneous Field Studies Map MF-1425-C, scale 1: 62,500.

*Wells, J.L., 1909, Mines of the Lordsburg district, New Mexico: Engineering and Mining Journal, v. 87, p. 890.

*Wells, E.H., and Wootton, T.P., 1932, *revised by* Wootton, T.P., Gold mining and gold deposits in New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 5, 24 p.

*Wells, E.H., and Wootton, T.P, 1940, Gold mining and gold deposits in New Mexico (revised ed.): New Mexico Bureau of Mines and Mineral Resources Circular 5, 25 p.

*Williams, F.E., 1966, Fluorspar deposits of New Mexico: U.S. Bureau of Mines Information Circular 8307, 143 p.

*Williams, S.A., 1978, Mineralization at Granite Gap, Hidalgo County, New Mexico, *in* Callender, J.F., Wilt, J.C., and Clemons, R.E., eds., Land of Cochise, Southeastern

Arizona: New Mexico Geological Society, *in cooperation with* Arizona Geological Society, 29th Annual Field Conference, p. 329-330.

*Wrucke, C.T., and Bromfield, C.S., 1961, Reconnaissance geologic map of part of the southern Peloncillo Mountains, Hidalgo County, New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map MF-160.

SIERRA RICA AND APACHE HILLS

Sierra Rica and Apache Hills are low, rounded hills with relief of about 305 m in the eastern bootheel area of Hidalgo County.

General Geology

Sierra Rica and Apache Hills are composed mainly of southwest-dipping strata of Cambrian-Ordovician to Pleistocene age. Paleozoic and Mesozoic rocks have been intruded by Laramide stocks and folded. Numerous northwest-trending thrust and normal faults are present. The predominant structure linking the two ranges is the Occidental anticline (Strongin, 1958), the axis of which trends northwest and west. A major normal fault, the Apache Hills fault, separates this anticline from folds to the northeast. Paleozoic rocks occur as thrust sheets over Mesozoic (Bisbee Group) sequences. Paleozoic sequences are interpreted by the sense of folding and faulting to be part of a northeast-verging thrust plate(Drewes, 1991).

Paleozoic rocks include Bliss Formation, El Paso Limestone, Montoya Group, Escabrosa Limestone, Paradise Formation, and Horquilla Limestone. Mesozic and Cenozoic rock units in the Sierra Rica and Apache Hills include the Bisbee Group (Cintura Formation, Mural Limestone, and Glance Conglomerate), Upper Cretaceous or lower Tertiary units (fanglomerate and igneous rocks), lower Tertiary intrusive rocks (diorite porphyry, quartz diorite porphyry, monzonite porphyry and quartz monzonite porphyry of the Apache Hills stock, and porphyritic rhyolite), and middle and upper Tertiary intrusive and volcanic rocks (latite porphyry, rhyolite prophyry, felsite, rhyolitic flows, tuffs, and breccia, quartz latite, numerous dike rocks, lamprophyre intrusive rocks, trachyte porphyry, and keratophyre intrusive rocks). Apache Hills caldera (Peterson, 1976; Deal and others, 1978) is a deeply eroded, 31-m..-old caldera filled with Chapo Formation and rhyoite of Wamels Pond. Apache Hill quartz monzonite may represent a resurgent phase of the volcano. Quaternary deposits include basalt and colluvial and alluvial deposits. Faulting took place during and after Laramide folding of the strata, during intrusive events and Basin-and-Range tectonism.

References

(* reference used in writing above summary)

*Deal, E.G., Elston, W.E., Erb, E.E., Peterson, S.L., Reiter, D.E., Damon, P.E., and

Shafiqullah, M., 1978, Cenozoic volcanic geology of the Basin and Range province in Hidalgo County, southwestern New Mexico, *in* Callender, J.F., Wilt, J.C., and Clemons, R.E., eds., Land of Cochise, Southeastern Arizona: New Mexico Geological Society, *in cooperation with* Arizona Geological Society, 29th Field Conference, p. 219-229.

*Drewes, Harald, 1989a, Description and development of the Cordilleran orogenic belt in the southwestern United States and northern Mexico: U.S. Geological Survey Professional Paper 1512, 92 p.

*Drewes, Harald, 1991a, Geologic map of the Big Hatchet Mountains, Hidalgo County, New Mexico: U.S. Geological Survey Miscellaneous Investigations Series Map I-2144, scale 1:24,000.

*Elston, W.E., 1960, Reconnaissance geologic map of Virden 30' quadrangle: New Mexico Bureau of Mines and Mineral Resources Geologic Map 15, scale 1:126,720.

Elston, W.E., 1965a, Mining districts of Hidalgo County, New Mexico, *in* Fitzsimmons, J.P., and Lochman-Balk, Christina, eds., Guidebook of southwestern New Mexico II: New Mexico Geological Society, 16th Field Conference, p. 210-214.

*Elston, W.E., 1983, Cenozoic volcanic centers in the New Mexico segment of the Pedregosa Basin; constraints on oil and gas exploration in southwestern New Mexico--Application of volcanology to petroleum exploration in southwestern New Mexico: Albuquerque, University of New Mexico report NMERDI 2-66-3104, 54 p.

Elston, W.E., Erb, E.E., and Deal, E.G., 1979, Tertiary geology of Hidalgo County, New Mexico; guide to metals, industrial minerals, petroleum, and geothermal resources: New Mexico Geology, v. 1, no. 1, p. 1-6.

*Griswold, G.B., Boy, R., Olson, R.R., and Zrinscak, P., 1989, Reconnaissance gold geochemical survey of five selected areas in southwestern New Mexico: New Mexico Bureau of Mines and Mineral Resources Open File Report OF-357, 19 p.

*Lasky, S.G., and Wootton, T.P., 1933, The metal resources of New Mexico and their economic features: New Mexico Bureau of Mines and Mineral Resources Bulletin 7, 178 p.

*Lindgren, W., Graton, L.C., and Gordon, C.H., 1910, The ore deposits of New Mexico: U.S. Geological Survey Professional Paper 68, 361 p.

*May, R.T., Smith, E.S., Dickson, R.E., and Nystrom, R.J., 1982, Douglas quadrangle, Arizona and New Mexico: Bendix Field Engineering Corporation, Grand Junction Operations, Report PGJ/F-118(82), 78 p.

*McLemore, V.T., 1983b, Uranium and thorium occurrences in New Mexico--Distribution, geology, production, and resources, with selected bibliography: New Mexico Bureau of

Mines and Mineral Resources Open File Report 183, 180 p.

*McLemore, V.T., 1996 (in press), Volcanic-epithermal precious-metal deposits in New Mexico, *in* Geology and ore deposits of the American Cordillera: Geological Society of Nevada.

*McLemore, V.T., and Lueth, V.W., 1995, Carbonate-hosted lead-zinc deposits in New Mexico: International Conference on Carbonate-Hosted Lead-Zinc Deposits [abs.]: Extended abstracts, Society of Economic Geologists, p. 209-211.

Peterson, S.L., 1976, Geology of the Apache No. 2 mining district, Hidalgo County, New Mexico: Albuquerque, University of New Mexico, unpublished Master's thesis, 86 p.

*Strongin, Oscar, 1958, Geology and ore deposits of Apache Hills and northern Sierra Rica, Hidalgo County, New Mexico: New York, Columbia University, unpublished Ph. D. dissertation, 221 p.

*Van Der Spuy, P.M., 1975, Geology and geochemical investigation of geophysical anomalies, Sierra Rica, Hidalgo County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Open File Report 62, --- p. [also unpublished Master's thesis, Golden, Colorado School of Mines, 1970].

Wade, W.R., 1914, Apache mining district, New Mexico: Engineering and Mining Journal, v. 87, no. 12, p. 597.

LUNA COUNTY

Luna County was established in 1901 from the western portion of Doña Ana County and was named after a prominent political figure of the times, Don Salomon Luna. Deming is the largest city and the county seat. The southern boundary is with Chihuahua, Mexico, and Columbus, New Mexico is an international port of entry. Three state parks are found in the county: Rockhound, Pancho Villa, and City of Rocks (**figure 1-2**).

CARRIZALILLO HILLS

Carrizalillo Hills are located along the southern border of Luna County with Mexico, near Hermanas (**figure 1-1**). The range extends into Mexico.

General Geology

Tertiary volcanic and volcaniclastic rocks of silicic to intermediate composition, volcanic necks, domes, and dikes, and conglomerate with limestone and granite clasts comprise the lowermost rocks of the northern Carrizalillo Hills in the U.S. Mid-Tertiary ignimbrite deposits are over 397 m thick, volcaniclastic layers are over 122 m thick, and an andesite intrusion and associated flows are over 183 m thick [**figure 4-3.1** (from Sillitoe and Bonham, 1984; Gates, 1985)]. Basal volcaniclastic rocks are inferred to be Oligocene in age, although no radiometric dating has been conducted on the rocks.

Fanglomerates that overlie the Tertiary rocks are probably Santa Fe Group sediments; a basal basalt is probably correlative with the Oligocene-early Miocene Uvas Andesite (Sierra de las Uvas) and Bear Springs Basalt (Black Range). The upper plugs, dikes, and flows are probably correlative to rocks of the Palomas volcanic field (Tres Hermanas Mountains). The youngest sequences are Quaternary pediment, fan, and arroyo deposits.

Carrizalillo Hills are an elongated, block-faulted uplift or horst that is bounded by northwest-trending and curved fault zones and internally disrupted by many smaller faults that generally trend northwesterly (Gates, 1985). Faults in the range generally are high-angle normal faults having insignificant amounts of strike-slip movement (**figure 4-3.1**).

Mineral Deposits

Carrizalillo mining district is in the Carrizalillo Hills (see McLemore and Sutphin, this volume).

References

(* reference used in writing above summary)

*Gates, E.E., 1985, The geology of the Carrizalillo Hills, Luna County, New Mexico: El Paso, University of Texas, Master's thesis, 133 p., scale 1:12,000.

*Griswold, G.B., 1961, Mineral deposits of Luna County, New Mexico: New Mexico Bureau of

Mines and Mineral Resources Bulletin 72, 157 p.

*Kottlowski, F.E., Foster, R.W., and Wengerd, S.A., 1969, Key oil tests and stratigraphic sections in southwest New Mexico, *in* Cordoba, D.A., Wengerd, S.A., and Shomaker, J., eds., Guidebook of the Border Region, Chihuahua and the United States: New Mexico Geological Society, 20th Annual Field Conference, p. 186-196.

*Leonard, M.L., 1982, The geology of the Tres Hermanas Mountains, Luna County, New Mexico: El Paso, University of Texas, unpublished Master's thesis, 105 p.

*Rupert, M.G., 1986, Structure and stratigraphy of the Klondike Hills, southwestern New Mexico: Las Cruces, New Mexico State University, unpublished Master's thesis, 138 p.

*Rupert, M.G., and Clemons, R.E., 1990, Stratigraphy and structure of the Klondike Hills, southwestern New Mexico: New Mexico Geology, v. 12, no. 2, p. 23-30.

*Seager, W.R., and Clemons, R.E., 1988, Geology of Hermanas quadrangle, Luna County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Geologic Map 63, scale 1:24,000.

Seager, W.R., Shafiqullah, M., Hawley, J.W., and Marvin, R., 1984, New K-Ar dates from basalt and the evolution of the southern Rio Grande rift: Geological Society of America Bulletin, v. 95, no. 1, p. 87-99.

*Thorman, C.H., and Drewes, H., 1981, Geologic map of the Gage SW quadrangle, Grant and Luna Counties, New Mexico: U.S. Geological Survey Miscellaneous Investigations Series Map I-1231, scale 1:24,000.

Varnell, R., 1976, Geology of the Hat Top Quadrangle, Luna County, New Mexico: El Paso, University of Texas, unpublished M.S. thesis, 62 p.

CEDAR MOUNTAINS

The Cedar Mountains are located northwest of the Carrizalillo Hills in Luna County.

General Geology

In the southern part of the Cedar Mountains, Paleozoic and Mesozoic sedimentary rocks crop out. Most of the range is composed of Oligocene latitic flows of Turkey Knob, rhyolite ash-flow tuffs, rhyolite plugs and dikes, latitic flows, and Miocene(?) olivine andesite. No vent areas have been recognized, but some units may have emanated from the Apache caldera (Clemons and Mack, 1988). The mountain range is cut by two sets of faults—(1) northwest-trending, high angle faults that cut pre-Tertiary (probably including Precambrian rocks in southwestern New Mexico) and Tertiary rocks, and (2) low-angle bedding-plane faults, typically concealed and interpreted as thrust faults (Corbitt and others, 1977; Thorman and Drewes, 1981). The low-angle bedding plate faults cut pre-Tertiary rocks, and may be related to the north- to northwest-verging

thrust fault system (Thorman and Drewes, 1981).

The northwest-trending high-angle faults have been described as basement-rooted faults that have been repeatedly reactivated in the Paleozoic and Tertiary time (Thorman and Drewes, 1981). Thorman and Drewes (1981) suggest that the low-angle faults were formed in Late Cretaceous or early Tertiary time, and may have been imbricate faults rooted near the Paleozoic-Precambrian basement boundary, forming in response to the Cordilleran orogenic events (Corbitt and Woodward, 1970, 1973). Alternatively, they suggest that the low–angle faults are related to, and may branch from, the complex Cedar Mountain Fault. This fault, a high-angle strike-slip fault, is located northwest of the Cedar Mountains and transects the Klondike Hills.

References

(* reference used in writing above summary)

*Bromfield, C.S., and Wrucke, C.T., 1961, Reconnaissance geologic map of the Cedar Mountains, Grant and Luna Counties, New Mexico: U.S. Geological Survey Mineral Investigations Field Studies Map MF-159, scale 1:62,500.

*Clemons, R.E., and Mack, G.H., 1988, Geology of southwestern New Mexico, *in* Mack, G.H., Lawton, T.F., and Lucas, S.G., ed., Cretaceous and Laramide tectonic evolution of southwestern New Mexico: New Mexico Geological Society, 39th Annual Field Conference, Deming, N. Mex., p. 45-57.

*Corbitt, L.L., and Woodward, L.A., 1973, Tectonic framework of the Cordilleran foldbelt in southwestern New Mexico: American Association of Petroleum Geologists Bulletin, v. 57, no. 11, p. 2207-2216.

*Kottlowski, F.E., Foster, R.W., and Wengerd, S.A., 1969, Key oil tests and stratigraphic sections in southwest New Mexico, *in* Cordoba, D.A., Wengerd, S.A., and Shomaker, J., eds., Guidebook of the Border Region; Chihuahua and the United States: New Mexico Geological Society, 20th Annual Field Conference, p. 186-196.

*Thorman, C.H., and Drewes, Harold, 1978, Geologic map of the Saltys quadrangle, Grant County, New Mexico: U.S. Geological Survey Miscellaneous Investigations Series Map I-1137, scale 1:24,000.

COOKES RANGE

The Cookes Range is located in southeastern Grant County and northern Luna County north of Deming and encompasses the Cookes Range WSA. Northern Cookes Range mining district is located in southeastern Grant County.

General Geology

The Cookes Range is a fault block of Precambrian through Mesozoic sedimentary rocks (the eastern part of the Burro Mountains uplift) that is intruded by a Laramide granodiorite plug (Cookes Peak stock) and by a later Tertiary pluton, and faulted (**figure 4-3.2**). Paleozoic rocks and granitic plutonic rocks are juxtaposed along the Sarten, Othello, East Cookes, and other unnamed faults. The range is separated from the Mimbres Range by a regional fault, the Cookes Peak fault, which is probably post-Cretaceous in age.

Precambrian rocks (in the southern part of the range at Fluorite Ridge) consist of granite, diorite, and amphibolite. Post-Precambrian formations include the Bliss Formation, El Paso Limestone, Montoya Group, Fusselman Dolomite, Percha Shale, Caballero Formation, Lake Valley Limestone, undifferentiated Pennsylvanian strata (12-61 m thick) containing Late Desmoinesian brachiopods and Early Missourian *Triticites* (Jicha, 1954; Elston, 1958), Abo Formation red beds, Sarten Sandstone, Colorado Formation, Macho Andesite, Rubio Peak Formation latite-andesite, Kneeling Nun Tuff, Mimbres Peak Formation, and Santa Fe Group/Gila Conglomerate and other flows and volcanics (458 m thick).

The Abo Formation, composed of limestone-chert conglomerate, is inferred to be a continental deposit, in contrast to the dominantly marine Hueco-Abo of the Robledo Mountains to the east. The Abo is unconformably overlain by Early Cretaceous Sarten Sandstone in the Cookes Range, whereas the Hueco-Abo of the Robledo Mountains to the east is overlain by Tertiary conglomerate.

Mineral Deposits

The Cookes Peak, Old Hadley, and Fluorite Ridge mining districts are in the Cookes Range.

References

(* reference used in writing above summary)

*Burchard, E.F., 1911, Fluorspar in New Mexico (Fluorite Ridge): Mining and Scientific Press, July 15, 1911, p. 74-76.

*Clarke, F.W., Hillebrand, W.F., Ransome, F.L., Penfield, S.L., Lindgren, W., Steiger, G., and Schaller, W.T., 1905, Plumbojarosite, Cooks Peak district, New Mexico, *in* Contributions to Mineralogy: U.S. Geological Survey Bulletin 262, p. 35-36.

*Clemons, R.E., 1982d, Geology of Florida Gap quadrangle, Luna County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Geologic Map 52, scale 1:24,000.

*Donegan, Ben, Donegan, Bob, Kottlowski, F.E., 1965, Road log from Nutt to Hillsboro, *in* Fitzsimmons, J.P., and Lochman-Balk, Christina, eds., 1965, Guidebook of southwestern

New Mexico II: New Mexico Geological Society, Sixteenth Field Conference, p. 27-30.

*Elston, W.E., 1957, Geology and mineral resources of Dwyer quadrangle, Grant, Luna, and Sierra Counties, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 38, 86 p.

*Farnham, L.L., 1961, Manganese deposits of New Mexico: U.S. Bureau of Mines Information Circular 8030, 176 p.

*Griswold, G.B., 1961, Mineral deposits of Luna County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 72, 157 p.

*Hall, R.B., 1978, World nonbauxite aluminum resources; alunite: U.S. Geological Survey Professional Paper 1076-A, 35 p.

*Hawley, J.W., and Kottlowski, F.E., 1965, Road log from Las Cruces to Nutt, *in* Fitzsimmons, J.P., and Lochman-Balk, Christina, eds., 1965, Guidebook of southwestern New Mexico II: New Mexico Geological Society, Sixteenth Field Conference, p. 15-27.

*Hill, G.T., 1994, Geochemistry of southwestern New Mexico fluorite deposits with possible base and precious metals exploration significance: Socorro, New Mexico Institute of Mining and Technology, M.S. thesis, 44 p.

*Jicha, H.L., Jr., 1954, Geology and mineral resources of Lake Valley quadrangle, Grant, Luna, and Sierra Counties, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 37, 93 p.

*Kottlowski, F.E., Foster, R.W., and Wengerd, S.A., 1969, Key oil tests and stratigraphic sections in southwest New Mexico, *in* Cordoba, D.A., Wengerd, S.A., and Shomaker, J., eds., Guidebook of the Border Region; Chihuahua and the United States: New Mexico Geological Society, 20th Annual Field Conference, p. 186-196.

*Loring, A.K., and Loring, R.B., 1980b, K/Ar ages of middle Tertiary igneous rocks from southern New Mexico: New Mexico Bureau of Mines and Mineral Resources, Isochron/West, no. 28, p. 17-19.

Lucas, S.G., Kues, B.S., Hayden, S.N., Allen, B.D., Kietzke, K.K., Williamson, T.W., Sealey, Paul, and Pence, Randy, 1988, Cretaceous stratigraphy and biostratigraphy, Cooke's Range, Luna County, New Mexico, *in* Mack, G.H., Lawton, T.F., and Lucas, S.G., eds., Cretaceous and Laramide tectonic evolution of southwestern New Mexico: New Mexico Geological Society, 39th Annual Field Conference, Guidebook, p. 143-167.

*McLemore, V.T., and Barker, J.M., 1985, Barite in north-central New Mexico: New Mexico Geology, v. 7, no. 2, p. 21-25.

*McLemore, V.T., and Lueth, V.W., 1995, Carbonate-hosted lead-zinc deposits in New Mexico:

International Conference on Carbonate-Hosted Lead-Zinc Deposits [abs.]: Extended abstracts, Society of Economic Geologists, p. 209-211.

Morris, R.W., 1974a, Geology and mineral deposits of the Northern Cook's Range, Grant County, New Mexico: El Paso, University of Texas, unpublished M.S. thesis, 48 p.

*Morris, R.W., 1974b, Geology and fluorspar deposits of the Northern Cook's Range, *in* Silver Anniversary Guidebook--Ghost Ranch, Central-northern New Mexico; Base metal and fluorspar districts of New Mexico--a symposium: New Mexico Geological Society, 25th Annual Field Conference, p. 381.

*Roswell Geological Society, 1958, Hatchet Mountains and the Cookes Range-Florida Mountains area, Roswell Geological Society Guidebook to 11th field conference, p. 79-86.

*Rothrock, H.E., Johnson, C.H., and Hahn, A.D., 1946, Fluorspar resources of New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 21, 239 p.

*Russell, P.L., 1947b, Exploration of the Fluorite Ridge fluorspar district, Luna County, New Mexico: U.S. Bureau of Mines Report of Investigations, 7 p.

Seager, W.R.,Clemons, R.E., Hawley, J.W., and Kelley, R.E., 1982, Geology of northwest part of Las Cruces 1˚x2˚ sheet, New Mexico: New Mexico Bureau of Mines and Mineral Resources Geologic Map 53, scale 1:125,000.

Soulé, J.H., 1946, Exploration of the White Eagle fluorspar mine, Cooke's Peak mining district, Grant County, New Mexico: U.S. Bureau of Mines, Report of Investigations RI-3903, 5p.

FLORIDA MOUNTAINS, LITTLE FLORIDA MOUNTAINS

Florida Mountains are a north-south–trending, east-tilted fault block located southeast of Deming. Little Florida Mountains are north of the Florida Mountains proper, and include Rockhound State Park. The ranges are located within the southern Mimbres Basin.

General Geology

Florida Mountains are located on the diffuse boundary between the Basin and Range structural province and the Rio Grande rift (Seager and Morgan, 1979). The mountains are composed of faulted Paleozoic strata that rest unconformably on granitic and metamorphic Precambrian rocks in the central part of the range and on metamorphosed Precambrian rocks in the northern part of the range (**figure 4-3.3**). A major alkalic igneous suite within the core of the range has been dated as latest Cambrian to earliest Ordovician; its occurrence documents the presence of lower Paleozoic alkalic plutons in southwestern New Mexico. The basement rocks may represent the projection of the Texas lineament zone to the northwest through the study area. The Late Cambrian to Early Ordovician pluton is in nonconformable contact with the Bliss Formation of similar age. A small exposure of diamictite (very poorly sorted, boulder

conglomerate —probably a mudflow deposit) described from the northwest Florida Mountains, rests unconformably on Precambrian basement and is unconformably overlain by the Bliss Formation.

Paleozoic rocks of the Florida Mountains include the Bliss Formation, El Paso Limestone and Montoya Group, Fusselman Dolomite, Percha Shale, Rancheria Formation, and the Hueco Group. Pennsylvanian and early Permian strata are missing owing to the "Florida Islands" positive between the Pedregosa Basin and Orogrande Basin (**figure 1-4**). The Hueco Group, thinned by erosion, is unconformable on the underlying Rancheria Formation. Mesozoic(?) and Cenozoic rocks include the Tertiary Lobo Formation, Rubio Peak Formation, dikes of varying compositions, the Mimbres conglomerate of Hernon and others (1953), and Quaternary deposits.

During Early Cretaceous and Late Cretaceous/Early Tertiary (Laramide) time, the Florida Mountains flanked the Burro Uplift (**figure 1-4**). The uplift is part of the extensive zone of northwest-trending features including the Deming axis, a major basement fault zone thought to be related to the Texas lineament.

According to Drewes (1989), in Late Cretaceous(?) or Paleocene(?) (Laramide) time, large-scale thrust faulting and overturning of beds took place along a basement fault zone, the South Florida Mountains reverse fault zone of Brown (1982) and Clemons (1985, 1989) (**figure 4-3.3**). Drewes (1989) suggests that the rocks record recurrent thrust- and reverse-fault movement within the Cordilleran orogenic belt, along with possible normal and strike-slip fault movement, and that the disruption is related to northeast-directed stresses of the Cordilleran orogeny. Other workers in the region (e.g., Brown, 1982) do not agree with the theory of thrust movement along the dêcollement, and instead consider the major reverse fault and other structures to relate to basement-cored block uplifts resulting from compression. In the latter part of Mesozoic time, strata were invaded by syenitic and related intrusives. Younger gabbroic sheets and mafic dikes intrude the syenitic rocks.

Block faulting during Tertiary time uplifted strata along range front faults and tilted the range to the east; earlier thrust faults of Cretaceous-early Tertiary (Laramide) age disrupt strata within the range [**figure 4-3.3**]. A major north–northeast– trending fault, the West Florida Mountains fault, is a range-bounding high–angle normal fault, probably activated during Miocene time, and probably active through Pleistocene time (Clemons, 1984, 1985). The fault is responsible for tilting of the Florida Mountains to the northeast after deposition of the Rubio Peak Formation. Other north-trending faults, folds, and breccia zones, probably related to Basin-and-Range activity, occur in the western part of the Florida Mountains. Tertiary intrusives and dikes cut the core of the range.

Little Florida Mountains are composed of (from base to top) Rubio Peak Formation, Little Florida Mountains andesite, rhyolite and ash flow tuffs, rhyolite intrusives and basaltic–andesite flows, Little Florida Mountains fanglomerate, and dacite, all of Tertiary age; Pliocene and Pleistocene Mimbres Conglomerate of Hernon and others (1953); and a capping of Pleistocene-Holocene unconsolidated conglomerate (Kiely and James, 1988).

At the northern edge of the Little Florida Mountains is Rock Hound State Park (**figure 1-2**), the first park established in the United States for amateur collection of mineral specimens. The park is within the volcanic section, and is composed of latite and tuff units that contain geodes and semiprecious gemstones including jasper, quartz crystals, amethyst, chalcedony, and opal. Rock and mineral specimens include manganese varieties (manganite, psilomelate, pyrolusite, wad, and manganiferous calcite), perlite and pitchstone, small crystals of feldspar and cristobalite, and flow-banded rhyolite.

Mineral Deposits

Florida Mountains and Little Florida Mountains mining districts are in the Florida and Little Florida ranges. Perlite is present in small quantities in the Little Florida Mountains. Zeolite and clay cements are common in the Little Florida Mountains fanglomerate (Keily and James, 1988). Agates, geodes, and jasper are collected from Rock Hound State Park. Total production is unknown. Early Paleozoic limestone in both districts are mostly dolomitic, but are locally of high-calcium grade (Kottlowski, 1962).

References

(* reference used in writing above summary)

*Bogart, L.E., 1953, The Hueco (Gym) Limestone, Luna County, New Mexico: University of New Mexico, M.S. thesis, 91 p.

Brookins, D.G., 1974, Radiometric age determinations from the Florida Mountains, New Mexico: Geology, v. 2, no. 11, p. 555-557.

Brookins, D.G., 1980, Geochronologic evidence for Paleozoic plutonic activity in Florida Mountains, New Mexico [abs.]: American Association of Petroleum Geologists Bulletin, v. 64, no. 5, p. 681-682.

*Brookins, D.G., 1980, Paleozoic plutonism from southern New Mexico--evidence from the Florida Mountains: Geophysical Research Letters, v. 7, no. 10, p. 741-744.

Brookins, D.G., and Corbitt, L.L., 1974, Preliminary Rb-Sr study of igneous rocks of the Florida Mountains, New Mexico [abs.]: American Geophysical Union, Transactions (EOS), v. 55, no. 4, p. 470-471.

Brookins, D.G., Rautman, C.E., and Corbitt, L.L., 1978, Uranium and thorium abundances and

whole rock chemistry of the Florida Mountains, New Mexico--Preliminary study: New Mexico Energy Institute Report 77-1104-C, 22 p.

Brookins, D.G., Rautman, C.E., and Corbitt, L.L., 1978, A study of silicic plutonic rocks in the Zuni and Florida Mountains to evaluate the possible occurrence of disseminated uranium and thorium deposits: Albuquerque, New Mexico Energy Institute Report 77-1104-C, 22 p.

*Brown, G.A., 1982, Geology of the Mahoney mine-Gym Peak area, Florida Mountains, Luna County, New Mexico: New Mexico State University, Master's thesis, 82 p.

*Brown, G.A., and Clemons, R.E., 1983, Florida Mountains section of southwest New Mexico overthrust belt--A reevaluation: New Mexico Geology, v. 5, no. 2, p. 26-29.

*Brown, G.A., and Clemons, R.E., 1983, Florida Mountains, southwest New Mexico--Part of Cordilleran overthrust belt or foreland block uplift? [abs.]: AAPG annual convention with divisions SEPM/EMD/DPA; American Association of Petroleum Geologists Bulletin, v. 67, no. 3, p. 432.

Clemons, R.E., 1982, Geology of Massacre Peak quadrangle, Luna County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Geologic Map 51, scale 1:24,000.

Clemons, R.E., 1982a, Volcanic development of Little Florida Mountains, southwest New Mexico [abs]: Geological Society of America Abstracts with Programs, v. 14, no. 3, p. 108.

*Clemons, R.E., 1982b, Petrography and age of plutonic rocks of Florida Mountains, New Mexico--Preliminary report: New Mexico Geology, v. 4, no. 3, p. 33-38.

*Clemons, R.E., 1982d, Geology of Florida Gap quadrangle, Luna County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Geologic Map 52, scale 1:24,000.

*Clemons, R.E., 1984, Geology of Capitol Dome quadrangle, Luna County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Geologic Map 56, scale 1:24,000.

*Clemons, R.E., 1985, Geology of Florida Gap quadrangle, Luna County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Geologic Map 52, scale 1:24,000.

*Clemons, R.E., 1985, Geology of South Peak quadrangle, Luna County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Geologic Map 59, scale 1:24,000.

Clemons, R.E., 1986b, Simplified geologic map of the Fanglomerate of Little Florida Mountains, *in* Hoffer, J., ed., Geology of southcentral New Mexico: El Paso Geological Society Guidebook 17, 165 p.

Clemons, R.E., 1987, Mineralization, alteration and igneous activity in the Florida Mountains, southwestern New Mexico: Socorro, Proceedings of New Mexico Geological Society Spring Meeting, p. 42.

*Clemons, R.E.,1989, Geology of the Florida Mountains, New Mexico, *in* Drewes, Harald, and Dyer, Russ, 1989, Tectonics of the eastern part of the Cordilleran Orogenic Belt, Chihuahua, New Mexico, and Arizona; Field Trip Guidebook T121, 28th International Geological Congress: American Geophysical Union, Washington, D.C., p. 16-24.

Clemons, R.E., in press, Geology of the Florida Mountains, southwest New Mexico: New Mexico Bureau of Mines and Mineral Resources Memoir 43, ---.

*Clemons, R.E., and Brown, G.A., 1983, Geology of Gym Peak quadrangle, Luna County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Geologic Map 58, scale 1:24,000.

Clemons, R.E., and Mack, G.H., 1988b, First-day road log, west flank of Florida Mountains, *in* Mack, G.H., Lawton, T.F., and Lucas, S.G., eds., Cretaceous and Laramide tectonic evolution of southwestern New Mexico: New Mexico Geological Society, 39th Annual Field Conference, Guidebook, p. 1-2.

*Corbitt, L.L., 1971, Structure and stratigraphy of the Florida Mountains, New Mexico: Albuquerque, University of New Mexico, unpublished Ph. D. dissertation, 115 p.

Corbitt, L.L., 1974, Structure and stratigraphy of the Florida Mountains, *in* Corbitt, L.L., ed., Geology of the Florida Mountains, Luna County New Mexico: El Paso Geological Society, Guidebook 8, p. 16-29.

*Corbitt, L.L., and Woodward, L.A., 1970, Thrust faults of the Florida Mountains, New Mexico, and their regional tectonic significance, *in* Woodward, L.A., ed., Guidebook of the Tyrone-Big Hatchet Mountains-Florida Mountains Region: New Mexico Geological Society, 21st Annual Field Conference, p. 69-74.

Corbitt, L.L., and Woodward, L.A., 1973, Upper Precambrian diamictite of Florida Mountains, southwestern New Mexico: Geological Society of America Bulletin, v. 84, no. 1, p. 171-173.

Corbitt, L.L., and Woodward, L.A., 1973, Tectonic framework of Cordilleran foldbelt in southwestern New Mexico: American Association of Petroleum Geologists Bulletin, v. 57, no. 11, p. 2207-2216.

Darton, N.H., 1917, Geologic Atlas of the U.S.; Deming folio: U.S. Geological Survey Folio 207.

*DeVaney, F.D., Fine, M.M., and Shelton, S.M., 1942, Manganese investigations-metallurgical division: U.S. Bureau of Mines Report of Investigations 3620, 9 p.

*Drewes, H., 1978, The Cordilleran orogenic belt between Nevada and Chihuahua: Geological Society of America Bulletin, v. 89, no. 5, p. 641-657.

*Drewes, Harald, 1991b, Description and development of the Cordilleran orogenic belt in the Southwestern United States and northern Mexico: U.S. Geological Survey Professional Paper 1512, 92 p.

Drewes, H., and Thorman, C.H., 1980, Geologic map of the Steins and part of the Vanar quadrangles, New Mexico and Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map I-1220, scale 1:24,000.

Drewes, H., and Thorman, C.H., 1980, Geologic map of the Cotton City quadrangle and the adjacent part of the Vanar quadrangle, Hidalgo County, New Mexico: U.S. Geological Survey Miscellaneous Investigations Series Map I-1221, scale 1:24,000.

Elston, W.E., 1970, Volcano-tectonic control of ore deposits, southwestern New Mexico, *in* Woodward, L.A., ed., Guidebook of the Tyrone-Big Hatchet Mountains-Florida Mountains Region: New Mexico Geological Society, 21st Annual Field Conference, p. 147-153.

*Evans, K.V., and Clemons, R.E., 1988, Cambrian-Ordovician (500 Ma) alkalic plutonism in southwestern New Mexico; U-Th-Pb isotopic data from the Florida Mountains: American Journal of Science, v. 288, no. 7, p. 735-755.

*Farnham, L.L., 1961, Manganese deposits of New Mexico: U.S. Bureau of Mines Information Circular 8030, 176 p.

Geissman, J.W., Jackson, M., Harlan, S.S., and Van-der-Voo, R., 1991, Paleomagnetism of latest Cambrian-Early Ordovician and latest Cretaceous-early Tertiary rocks of the Florida Mountains, southwest New Mexico: Journal of Geophysical Research, v. 96, no. 4, p. 6053-6071.

*Griswold, G.B., 1961, Mineral deposits of Luna County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 72, 157 p.

Griswold, G.B., 1974, Mineral deposits, Florida Mountains, *in* Corbitt, L.L., ed., Geology of the Florida Mountains, Luna County New Mexico: El Paso Geological Society, Guidebook 8, p. 30-35.

James, H.L., and McCall, W.B., 1965, Exit road log from Lordsburg to Las Cruces, *in* Fitzsimmons, J.P., and Lochman-Balk, Christina, eds., Guidebook of southwestern New Mexico II: New Mexico Geological Society, 16th Field Conference, p. 76-81.

*Kieley, J.M., and James, W.C., 1988, Diagenesis of the fanglomerate of Little Florida Mountains (Miocene), southwestern New Mexico, *in* Mack, F.H., Lawton, T.F., and Lucas, S.G., eds., Cretaceous and Laramide tectonic evolution of southwestern New Mexico: New Mexico Geological Society Guidebook, 39th Field Conference, p. 175-184.

*Kottlowski, F.E., 1958, Pennsylvanian and Permian rocks near the late Paleozoic Florida islands, *in* Hatchet Mountains and the Cookes Range-Florida Mountains area: Roswell Geological Society, Guidebook to 11th Field Conference, p. 79-86.

*Kottlowski, F.E., 1963, Paleozoic and Mesozoic strata of southwest and south-central New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 79, 100 p.

Kottlowski, F.E., 1971, Paleozoic geologic history of southwest New Mexico and northern Chihuahua tectonic belt, *in* K. Seewald and D. Sundeen, eds., The geologic framework of the Chihuahua tectonic belt: West Texas Geological Society, Publication 71-59, p. 25-37.

Kottlowski, F.E., LeMone, D.V., and Foster, R.W., 1969, Early Ordovician highlands of Precambrian rocks and their associated facies: El Paso Geological Society, Guidebook to 3rd Field Conference, p. 134-142.

*Kottlowski, F.E., Foster, R.W., and Wengerd, S.A., 1969, Key oil tests and stratigraphic sections in southwest New Mexico, *in* Cordoba, D.A., Wengerd, S.A., and Shomaker, J., eds., Guidebook of the Border Region; Chihuahua and the United States: New Mexico Geological Society, 20th Annual Field Conference, p. 186-196.

Lasky, S.G., 1940, Manganese deposits in the Little Florida Mountains, Luna County, New Mexico; a preliminary report: U.S. Geological Survey Bulletin 922-C, p. 55-73.

Lemly, I.S., 1982, The Lobo Formation and lithologically similar units in Luna and southwestern Doña Ana Counties, New Mexico: New Mexico State University, Master's thesis, 95 p.

LeMone, D.V., 1974, The Lower Ordovician Florida Mountains Formation stratotype, Luna County, New Mexico, *in* Corbitt, L.L., ed., Geology of the Florida Mountains, Luna County New Mexico: El Paso Geological Society, Guidebook 8, p. 36-46.

*Lochman-Balk, C., 1958, The Capitol Dome section, Florida Mountains: Roswell Geological Society, 1958, Guidebook of the Hatchet Mountains and the Cooks Range-Florida Mountain areas, Grant, Hidalgo and Luna Counties, southwestern New-Mexico, 11th Field Conference, May 14, 15, and 16, 1958, p. 43-52.

Lochman-Balk, C., 1958, The Capitol Dome section, Florida Mountains, *in* Corbitt, L.L., ed., Geology of the Florida Mountains, Luna County New Mexico: El Paso Geological Society, Guidebook 8, p. 7-15.

Loring, A.K., and Armstrong, D.G., 1980, Cambrian-Ordovician syenites of New Mexico, part of a regional alkalic intrusive episode: Geology, v. 8, no. 7, p. 344-348.

Lynn, G.C., 1975, Stratigraphic correlation of the El Paso and Montoya Groups in the Victorio Mountains, the Snake Hille, and the Big Florida Mountains in southwestern New Mexico: Tucson, University of Arizona, M.S. thesis, 115 p.

Matheney, R.K., and Brookins, D.G., 1983, Geochronologic studies of igneous rocks from Florida Mountains, New Mexico [abs.]: New Mexico Geology, v. 5, p. 57.

Matheney, R.K., and Brookins, D.B., 1989, Two models for resetting of Rb-Sr isochron dates of Cambrian red-rock granophyres, Florida Mountains, New Mexico; A test using oxygen isotopes [abs.]: Geological Society of America Abstracts with Programs, v. 21, no. 5, p. 112.

Matheney, R.K., Brookins, D.G., Wallin, E.T., Shafiqullah, M., and Damon, P.E., 1990, Incompletely reset Rb-Sr systems from a Cambrian red-rock granophyre terrane, Florida Mountains, New Mexico, USA: Chemical Geology; Isotope Geoscience Section, v. 86, no. 1, p. 29-47.

*Matheney, R.K., Shafiqullah, M., Brookins, D.G., Damon, P.E., and Wallin, E.T., 1988, Geochronologic studies of the Florida Mountains, New Mexico, *in* Mack, F.H., Lawton, T.F., and Lucas, S.G., eds., Cretaceous and Laramide tectonic evolution of southwestern New Mexico: New Mexico Geological Society Guidebook, 39th Field Conference, p. 99-107.

*McAnulty, W.N., 1978, Fluorspar in New Mexico: New Mexico Bureau of Mines and Mineral Resources Memoir 34, 64 p.

*North, R.M., and Tuff, M.A., 1986, Fluid-inclusion and trace-element analyses of some barite-fluorite deposits in south-central New Mexico; in Clemons, R.E., King, W.E., and Mack, G.H., eds., Truth or Consequences Region: New Mexico Geological Society, Guidebook to the 37th field conference, p. 301-306.

*Roswell Geological Society, 1958, Guidebook of the Hatchet Mountains and the Cooks Range - Florida Mountain areas, Grant, Hidalgo, and Luna Counties, southwestern New-Mexico: 11th Field Conference, May 14, 15, and 16, 1958, 140 p.

*Rothrock, H.E., Johnson, C.H., and Hahn, A.D., 1946, Fluorspar resources of New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 21, 239 p.

*Seager, W.R., and Mack, G.H., 1986, Laramide paleotectonics of southern New Mexico, *in* Peterson, J.A., ed., Paleotectonics and Sedimentation in the Rocky Mountain Region, United States: American Association of Petroleum Geologists Memoir 41, p. 669-685.

*Weber, R.H., 1980, Rock Hound: New Mexico Geology, v. 2, no. 4, p. 59-60.

*Wengerd, S.A., 1970, Petroleum prospects in southwesternmost New Mexico, *in* Woodward, L.A., ed., Guidebook of the Tyrone-Big Hatchet Mountains-Florida Mountains Region: New Mexico Geological Society, 21st Annual Field Conference, p. 91-104.

*Williams, F.E., Fillo, P.V., and Bloom, P.A., 1964, Barite deposits of New Mexico: New

Mexico Bureau of Mines and Mineral Resources Circular 76, 46 p.

*Woodward, L.A.,1970, ed., Guidebook of the Tyrone-Big Hatchet Mountains-Florida Mountains Region: New Mexico Geological Society, 21st Annual Field Conference, 162 p.

*Woodward, L.A., 1970, Precambrian rocks of southwestern New Mexico, *in* Woodward, L.A., ed., Guidebook of the Tyrone-Big Hatchet Mountains-Florida Mountains Region: New Mexico Geological Society, 21st Annual Field Conference, p. 27-31.

GOOD SIGHT MOUNTAINS/UVAS VALLEY

Good Sight Mountains/Uvas Valley area lies west of the Rio Grande within the rift and west of Las Cruces (**figure 1-10**).

General Geology

The Good Sight Mountains and Uvas Valley area, composed of rock units that range in age from Eocene to Holocene (mostly late Eocene-early Oligocene Rubio Peak Formation)(Seager, 1975), forms the west limb of the northward-plunging Uvas Valley syncline (the Sierra de las Uvas forms the east limb) and the Good Sight-Cedar Hills depression (Seager, 1975) (**figure 4-3.4**.). Good Sight-Cedar Hills depression (Seager, 1973, 1975), an Oligocene to Miocene feature, lies within and parallel to the Rio Grande rift in western Doña Ana County and eastern Luna County, extending from the Good Sight Mountains on the west to the Cedar Hills on the east. It is 80 km long and 40 km wide, has a raised rim east of the Cedar Hills vent zone, and is filled with volcanic tuffs, flows, and related clastic rocks of the 33-39-m.y.-old Bell Top Formation and 26 m.y. old Uvas Andesite.

The Rubio Peak Formation consists of latite-andesite volcaniclastic rocks, flows, dikes, plugs, and small stocks. It has been subdivided into seven units in the Good Sight Mountains area by Clemons (1979). The Rubio Peak Formation probably overlies Permian rocks and is unconformably overlain by the Uvas Andesite and volcaniclastic rocks of the Bell Top Formation. The Bell Top has been subdivided into 13 informal members (Clemons, 1976) separated by unconformities. Units are nowhere present in their entireity. Distribution corresponds to the Cedar Hills-Good Sight Mountains depression, including the central Sierra de las Uvas (as much as 458 m thick), Cedar Hills (over 488 m thick), San Diego Mountain [Tonuco Uplift and west Selden Hills (214 m thick)], Sleeping Lady Hills, and Rough and Ready Hills. Lesser thicknesses occur in the Rincon Hills and Good Sight Mountains. The Bell Top pinches out in northern West Potrillo Mountains and occurs near the surface in the Jornada del Muerto. Bell Top rhyolite and quartz latite flows are interbedded with volcaniclastic sandstone, tuff, and pumice in the Good Sight Mountains. In the northern part of the range (north of Nutt), the Rubio Peak Formation is

unconformably overlain by the Kneeling Nun Tuff, younger andesites and latites, and the Uvas Andesite. Uvas Andesite fills the Good Sight-Cedar Hills depression and forms the central resurgent dome in the Sierra de las Uvas hills. More than 92 m of Quaternary deposits, which unconformably overlie the Rincon Valley Formation (Santa Fe Group), fill the Uvas Valley east of the range.

The Good Sight Mountains contain dikes, plugs, stocks, and massive intrusive-extrusive complexes (Clemons, 1979) clustered in a north-trending zone that is 48 km long and 6.5 km wide. The zone has been named the Good Sight Mountains vent zone (probably a zone of coalescing vents and conduits) (Clemons, 1979). The vent zone may be contemporaneous with the Cedar Hills vent zone. A normal fault is inferred along the west side of the range (Seager, 1975; Ramberg and others, 1978). Although no direct surficial or geophysical evidence supports its occurrence. A northeast-trending fault is exposed in the northern part of the range that is one of several en echelon faults extending from Deming to the Caballo Mountains (Clemons, 1979).

In his summary of proposed mid-Tertiary calderas in southwestern New Mexico, Elston (1984) describes the Good Sight-Cedar Hills area as an elongated, asymmetrical, shallow volcano-tectonic depression, having vents and domes on its east side and a hinge zone on the west side.

Mineral and Energy Resources

Nutt Mountain (north end of Good Sight Mountains) is a perlitic rhyolite dome similar to Picacho Mountain near Las Cruces. Clay (bentonite) has been mined from the Camp Rice Formation near the Sierra-Doña Ana County line. Sand and gravel from the Camp Rice Formation and from eolian deposits as well as surficial caliche deposits are quarried for local use in highway maintenance and other construction purposes.

References

(* reference used in writing above summary)

*Clemons, R.E., 1979, Geology of Good Sight Mountains and Uvas Valley, southwest New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 169, 32 p., scale 1:48,000.

*Elston, W.E., 1984a, Mid-Tertiary ash flow tuff cauldrons, southwestern New Mexico: Journal of Geophysical Research, v. 89, no. 10, p. 8733-8750.

*Hawley, J.W., and Kottlowski, F.E., 1965, Road log from Las Cruces to Nutt, *in* Fitzsimmons, J.P., and Lochman-Balk, Christina, eds., 1965, Guidebook of southwestern New Mexico II: New Mexico Geological Society, Sixteenth Field Conference, p. 15-27.

*James, H.L., and McCall, W.B, 1965, Exit roadlog from Lordsburg to Las Cruces, *in*

Fitzsimmons, J.P., and Lochman-Balk, Christina, eds., 1965, Guidebook of southwestern New Mexico II: New Mexico Geological Society, Sixteenth Field Conference, p. 86-92.

*Ramberg, I.B., Cook, F.A., and Smithson, S.B., 1978, Structure of the Rio Grande Rift in southern New Mexico and West Texas based on gravity interpretation: Geological Society of America Bulletin, v. 89, no. 1, p. 107-123.

*Seager, W.R., 1973, Resurgent volcano-tectonic depression of Oligocene age, south-central New Mexico: Geological Society of America Bulletin, v. 84, p. 3611-3626.

*Seager, W.R., 1975, Cenozoic tectonic evolution of the Las Cruces area, New Mexico, *in* Seager, W.R., Clemons, R.E., and Callender, J.F., eds., Guidebook of the Las Cruces Country: New Mexico Geological Society Guidebook, 26th Field Conference, p. 241-250.

Seager, W.R.,Clemons, R.E., Hawley, J.W., and Kelley, R.E., 1982, Geology of northwest part of Las Cruces 1˚x 2˚ sheet, New Mexico: New Mexico Bureau of Mines and Mineral Resources Geologic Map 53, scale 1:125,000.

GRANITE HILL

Granite Hill rises 76 m above the pediment southwest of the West Potrillo Mountains on the eastern edge of the Mimbres Basin in southeast Luna County; Mesilla Basin lies to the east (**figure 1-1**). Granite Hill is within the Rio Grande rift zone on the western edge of the West Potrillo volcanic field, is part of a volcano-tectonic horst within the Mesozoic Chihuahua Trough (Dickinson, 1981) and is located along the projection of the Texas lineament zone (**figure 1-4**).

General Geology

Granite Hill is an uplifted, andesite-cored feature composed of north-trending and east-dipping (30˚ E.) Precambrian granite and overlying marine sedimentary rocks up to 232 m thick, consisting of Cretaceous conglomerate, limestone, and sandstone deposits (**figure 4-3.5**). Fault activity uplifted the hill during Basin-and-Range extension. A Tertiary andesite dike, a northeast-trending feature, is the main structural feature of the area and is associated with faulting. Faults trend into the main andesite body.

Intrusive andesite of Granite Hill is similar petrologically to the Mount Riley-Mount Cox intrusion in the East Potrillo Mountains. Tilting of the pre-intrusive units, the intrusive event, and the faulting are the result of both Laramide and Basin-and-Range tectonism.

Mineral Resources

Camel Mountain-Eagle Nest occurrences are in the Granite Hill area (see McLemore and Sutphin, this volume). Although several test wells were drilled in the region, no oil and gas shows were recorded.

References

(* reference used in writing above summary)

*Broderick, J.C., 1984, The geology of Granite Hill, Luna County, New Mexico: El Paso, University of Texas, unpublished Master's thesis, 90 p.

*Gese, D.D., 1985, Mineral resources of the West Potrillo Mountains/Mt. Riley (NM-030-052) Study Area and the Aden Lava Flow (NM-030-053) Wilderness Study Area, Doña Ana and Luna Counties, New Mexico: U.S. Bureau of Mines Open File Report MLA 74-85, 19 p.

*Griswold, G.B., 1961, Mineral deposits of Luna County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 72, 157 p.

*Seager, W.R., 1989, Geology beneath and around the West Potrillo basalts, Doña Ana and Luna Counties, New Mexico: New Mexico Geology, v. 11, no. 3, p. 53-59.

Seager, W.R., and Mack, G.H., 1990, Eagle Nest-Granite Hill area, Luna County, New Mexico--A new look at some old rocks: New Mexico Geology, v. 12, p. 1-7, 19.

KLONDIKE HILLS

(See also Carrizalillo Hills/Cedar Mountains)

The Klondike Hills are low hills located northeast of the Cedar Mountains, western Luna County (**figure 1-1**).

General Geology

Precambrian granitic basement rocks crop out in the northwest-trending Klondike Hills, but the majority of exposed rocks, exclusive of Quaternary pediment and alluvium, are composed of the Bliss Formation, El Paso Limestone, Cable Canyon Sandstone (Montoya Group), Fusselman Dolomite, Percha Shale, Keating and Hachita Formations (Escabrosa Group), Horquilla Limestone, Ringbone(?) Formation, and Tertiary rhyolite pyroclastic rocks and tuffs (**figure 4-3.6**)

According to Corbitt (1978), the Klondike Hills were formed during Basin and Range faulting. However, within the range, a series of complex thrust faults exposes the Laramide features. The hills contain west-northwest-trending folds, some overturned to the north. The hills are located at the northern margin of the Cordilleran foldbelt (Corbitt and Woodward, 1973).

Rocks are cut by northwest- and northeast-trending fault sets, both high-angle and low-angle. Northwest–trending, curvilinear Cedar Mountain fault has variable dip and has as much as 610 m of vertical offset, although left-lateral offset is suggested by drag folds, and wide, brecciated zones (Rupert, 1988). Exposed low-angle faults and complex folds may be thrust faults or low-angle normal listric faults (Rupert, 1988). Although controversial and differing from the earlier analysis by Corbitt and others (1978), Rupert suggests that evidence of the deformational

style in Laramide time is consistent with proposed basement-cored block uplift and strike-slip motion within the Texas lineament zone, and later tilting and small–scale faulting during extensional events in the Rio Grande rift zone. According to Rupert (1988), evidence for this conclusion is the dominantly vertical motion along the basement-cored Cedar Mountain fault and the associated minor thrust faults produced by drag during uplift.

Mineral Resources

Major Paleozoic limestone units crop out in the Klondike Hills and may be sources of high calcium limestone deposits.

References

(* reference used in writing above summary)

*Armstrong, A.K., 1970, Mississippian stratigraphy and geology of the northwestern part of the Klondike Hills, southwestern New Mexico, *in* Woodward, L.A., ed., Guidebook of the Tyrone-Big Hatchet Mountains-Florida Mountains Region: New Mexico Geological Society, 21st Annual Field Conference, p. 59-63.

*Corbitt, L.L., Nials, F.L., and Varnell, R.J., 1978, Laramide thrust faulting, Klondike Hills, southwestern New Mexico, *in* Callender, J.F., Wilt, J.C., Clemons, R.E., and James, H.L., eds., Land of Cochise, southeastern Arizona: New Mexico Geological Society with the Arizona Geological Society, 29th Field Conference Guidebook, p. 297-300.

*Corbitt, L.L., and Woodward, L.A., 1973a, Tectonic framework of the Cordilleran foldbelt in southwestern New Mexico: American Association of Petroleum Geologists Bulletin, v. 57, no. 11, p. 2207-2216.

*Kottlowski, F.E., Foster, R.W., and Wengerd, S.A., 1969, Key oil tests and stratigraphic sections in southwest New Mexico, *in* Cordoba, D.A., Wengerd, S.A., and Shomaker, J., eds., Guidebook of the Border Region, Chihuahua and the United States: New Mexico Geological Society, 20th Annual Field Conference, p. 186-196.

Rupert, M.G., 1986, Structure and stratigraphy of the Klondike Hills, southwestern New Mexico: Las Cruces, New Mexico State University, unpublished M.S. thesis, 138 p.

*Rupert, M.G., 1988, Klondike Hills, southwestern New Mexico--Evidence for Laramide strike-slip deformation, *in* Mack, F.H., Lawton, T.F., and Lucas, S.G., eds., Cretaceous and Laramide tectonic evolution of southwestern New Mexico: New Mexico Geological Society, 39th Annual Field Conference, Deming, N. Mex., p. 16-25.

*Rupert, M.G., and Clemons, R.E., 1990, Stratigraphy and structure of the Klondike Hills, southwestern New Mexico: New Mexico Geology, v. 12, no. 2, p. 23-30.

*Thorman, C.H., and Drewes, Harald, 1981, Geologic map of the Gage SW quadrangle, Grant

and Luna Counties, New Mexico: U.S. Geological Survey Miscellaneous Investigations Series Map I-1231, scale 1:24,000.

MIMBRES BASIN

Mimbres Basin is a major basin of the Rio Grande Rift in southern New Mexico (**figure 1-10**). The basin is bounded on the southeast by the West Potrillo Mountains, a large volcanic field, and extends northward along the Mimbres River to west of the Cookes Range.

General Geology

The north-trending eastern boundary fault of the Mimbres Basin is rift-related, and has a stratigraphic separation of as much as 1,220 m (Kottlowski and others, 1969). Examination of wildcat exploration holes in the vicinity of Deming shows that the Mimbres Basin is filled to a depth of about 1,220 m with middle Pleistocene and older fluvial, alluvial-fan, and playa deposits (Clemons, 1986; Seager, in press; J.W. Hawley, written commun., *in* Contaldo and Mueller, 1988). Prior to Laramide time, the area was part of the Florida Moyotes Uplift (**figure 1-4**), and before development of Basin and Range faulting, the area was covered with volcanic rocks of Eocene to Miocene age, which provided a source for later basin fill. Tertiary rocks rest unconformably on Precambrian basement.

Sand and gravel deposits in the basin form the major aquifer for the region (Charles V. Theis, *in* U.S. Geological Survey, 1991, p. 16-18). Recharge is by seepage from the present-day rivers (mainly the Mimbres River and San Vicente Arroyo) and by runoff from the Black Range, Mimbres Mountains, Cookes Range, and Florida Mountains. In the Mimbres Basin south of Deming, tension cracks have formed as a result of ground-water withdrawal from this aquifer and have resulted in land subsidence [from 1910 until 1983, the water table was lowered more than 34 m (Contaldo, 1988)]. Eroded tension cracks result in fissures at the surface in 12 distinct areas; they are dependent on soil type, soil thickness, and amount of water table drawdown. Fissures have various ground patterns (orthogonal, polygonal, and curvilinear) that are enhanced by weathering processes. Depressions form near the fissures, and are subsequently infiltrated by surface water and eventual collapse. Large, elongate, gullies and associated tributary gullies form by percolation by surface water, the largest observed being 10 m in width and 13 m or more in depth. Fissure formation results in damage to man-made structures, including buildings, roads, and water wells, and increased hazards associated with surface soil collapse and ground water contamination.

Mimbres Valley, named for the prehistoric Mimbres people, contains evidence of prehistoric dwellings. In historic time, Mimbres Valley was the last stronghold of the Apache tribe.

Mineral Resources

Mimbres Hot Springs is a group of nearly 30 springs with a combined flow above 100 gpm and a temperature of 137˚F. Fluorine content of the hot springs is high (about 16 ppm).

References

(* reference used in writing above summary)

Cameron, C.M., 1994, The destruction of the past--Nonrenewable cultural resources: Nonrenewable Resources, v. 3, no. 1, p. 6-24.

Clemons, R.E., 1986, Petrographic analysis of cuttings and interpretive stratigraphy of Seville-Trident exploration wells near Deming, New Mexico: New Mexico Geology, v. 8, p. 5-11.

Clemons, R.E., 1986, Petrography and stratigraphy of Seville-Trident exploration wells near Deming, New Mexico: New Mexico Geology, v. 8, no. 1, p. 5-11.

Contaldo, G.J., 1986, Earth fissures in the Deming area, Luna County, New Mexico [abs.]: New Mexico Geology, v. 8, no. 3, p. 70.

*Contaldo, G.J., 1989, Earth fissures and land subsidence near Deming, New Mexico: Las Cruces, New Mexico State University, unpublished Master's thesis, 106 p.

*Contaldo, G.J., and Mueller, J.E., 1988; Earth fissures in the Deming area, *in* Mack, F.H., Lawton, T.F., and Lucas, S.G., eds., Cretaceous and Laramide tectonic evolution of southwestern New Mexico: Guidebook, New Mexico Geological Society, 39th Annual Field Conference, p. 3-4.

Doty, G.C., 1959, Mimbres Valley, Luna County, *in* Annual water level measurements in observation wells, 1951-1955, and atlas of maps showing changes of water levels for various periods from beginning of record through 1954: New Mexico State Engineer Technical Report no. 13, p. 299-339.

Elston, W.E., 1965, Volcanic rocks of the Mimbres and upper Gila drainages, New Mexico, *in* Fitzsimmons, J.P., and Lochman-Balk, Christina, eds., Guidebook of southwestern New Mexico II: New Mexico Geological Society, 16th Field Conference, p. 167-179.

*Elston, W.E., and Netelbeek, T.A., 1965, Road log from Mimbres Valley to Silver City, *in* Fitzsimmons, J.P., and Lochman-Balk, Christina, eds., Guidebook of southwestern New Mexico II: New Mexico Geological Society, 16th Field Conference, p. 31-35.

*Friesen, R.L., 1992, Digital documentation of deformation and groundwater levels near an earth fissure in the Mimbres Basin, New Mexico [abs.]: New Mexico Geological Society Proceedings Volume, 1992 Annual Spring Meeting, p. 19. (*also* New Mexico Geology, v. 14, no. 3, p. 63.)

*Kottlowski, F.E., Foster, R.W., and Wengerd, S.A., 1969, Key oil tests and stratigraphic sections in southwest New Mexico, *in* Cordoba, D.A., Wengerd, S.A., and Shomaker, J., eds., Guidebook of the Border Region; Chihuahua and the United States: New Mexico Geological Society, 20th Annual Field Conference, p. 186-196.

*Kuellmer, F.J., and Kottlowski, F.E., 1965, Road log from Hillsboro to Mimbres Valley, *in* Fitzsimmons, J.P., and Lochman-Balk, Christina, eds., Guidebook of southwestern New Mexico II: New Mexico Geological Society, 16th Field Conference, p. 31-35.

*Lucas, S.G., 1988, The "Deming Dinosaur" was a mammoth, *in* Mack, F.H., Lawton, T.F., and Lucas, S.G., eds., Cretaceous and Laramide tectonic evolution of southwestern New Mexico: New Mexico Geological Society Guidebook, 39th Field Conference, p. 12-13.

McLean, J.S., 1977, Hydrologic maps and data in the Mimbres Basin, New Mexico: U.S. Geological Survey Open-File Report 77-314, 531 p., scale 1:48,000.

Seager, W.R., 1992??, Geology of southwest quarter of Las Cruces and northwest El Paso 1° x 2° sheets, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Geologic Map 60, scale 1:125,000.

Swanberg, C.A., 1982, Deep thermal structure of Mimbres Basin, New Mexico--Implications for oil and gas potential [abs.]: American Association of Petroleum Geologists Bulletin, v. 66, no. 10, p. 1701.

Swanberg, C.A., Sander, R., Marvin, P.R., Daggett, P., Young, C.T., and Morgan, P., 1981, Geophysical/geothermal studies in the southeastern Mimbres Basin near the City of Columbus, southern Rio Grande Rift, New Mexico, *in* Hoffer, J.M., and Hoffer, R.L., eds., Geology of the border, southern New Mexico-northern Chihuahua: El Paso Geological Society, p. 91-96.

*U.S. Geological Survey, 1991, Short papers on water resources in New Mexico, 1937-1957, prepared in cooperation with State Engineer of New Mexico, U.S. Corps of Engineers, U.S. Army, Defense Plant Corporation, and the U.S. Atomic Energy Commission: U.S. Geological Survey Open-File Report 91-81, 77 p.

TRES HERMANAS MOUNTAINS

General Geology

Located in southern Luna County, the Tres Hermanas Mountains are composed of the Fusselman Dolomite, Escabrosa Limestone and undifferentiated Pennsylvanian rocks, which are unconformable with the overlying Hueco Group. Early Cretaceous clastic rocks and limestone unconformably overlie the Paleozoic units. Tertiary rocks include (1) a latite breccia, (2) tuff and subordinate flows, (3) andesite flows and intrusives, (4) quartz monzonite intrusive stock (Tres

Hermanas stock) containing highly silicified xenoliths of Paleozoic and Cretaceous country rocks, (5) numerous monzonite, rhyolite, and latite dikes that intrude both the andesite flows and intrusives and the quartz monzonite stock, and (6) quartz latite and rhyolite intrusive rocks. Quartz latite and rhyolite intrusives are separated from older rocks by an unconformity.

Locally, the Paleozoic rocks have undergone contact metamorphism and show evidence of mild compressive deformation (Drewes, 1989). Seager (1983) suggests that the extensive Paleozoic section exposed in the Tres Hermanas Mountains is evidence for a broad, basement–cored Laramide uplift that extends from the Tres Hermanas Mountains to Fluorite Ridge (southern part of the Cookes Range), known as the Florida Uplift. Pleistocene olivine basalt flows and dikes are present at Black Top Mountain and in the southwestern part of the range.

A northwest-trending thrust-fault block has been described by Drewes (1989) in the West Lime Hills. The block is composed of Permian sequences (Epitaph Dolomite and Colina Limestone) thrust over Lower Cretaceous rocks (Cintura Formation, Bisbee Group). According to Drewes (1989), the thrust fault is a low- to moderate-angle feature that is locally concealed by alluvium.

Late Cenozoic olivine basalt and associated andesite and trachyte of the Palomas volcanic field occur in the southern Tres Hermanas Mountains and extend into the Sierra Boca Grande of Mexico. As many as 30 cinder cones are exposed in the volcanic field. According to Frantes and Hoffer (1982), the olivine basalts are older than those within the Rio Grande Rift to the east and include more highly differentiated members than rift basalts. The olivine basalts are younger than the andesite and trachyte. Volcanic features include lava-capped cinder cones, basalt dikes, and pillow basalt structures. Flows are partially covered by eolian sand.

Mineral Resources

Tres Hermanas mining district occurs in the Tres Hermanas Mountains (see McLemore and Sutphin, this volume). The area has potential for high-calcium limestone and travertine.

References

(* reference used in writing above summary)

*Balk, Robert, 1961, Geologic map of Tres Hermanas Mountains: New Mexico Bureau of Mines and Mineral Resources Geologic Map 16, scale 1:48,000.

Doraibabu, Peethambaram, 1971, Trace base metals, petrography, rock alteration of the productive Tres Hermanas stock, Luna County, New Mexico: Rolla, University of Missouri, Ph. D. dissertation, unknown p.

*Doraibabu, P. and Proctor, P.D., 1972, Zinc-lead-copper trace contents in Tres Hermanas stock, Luna County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Target

Exploration Report E-4, 9 p.

Doraibabu, Peethambaram, and Proctor, P.D., 1973, Trace base metals, petrography, and alteration of the Tres Hermanas stock, Luna County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Geologic Map 132, 29 p.

*Drewes, H., 1989, Description and development of the Cordilleran orogenic belt in the southwestern United States and northern Mexico: U.S. Geological Survey Professional Paper 1512, 92 p.

Frantes, T.J., 1981, The geology of the Palomas Volcanic Field, Luna County, New Mexico and Chihuahua, Mexico: El Paso, University of Texas, unpublished M.S. thesis, 70 p.

*Frantes, T.J., and Hoffer, J.M., 1982, Palomas volcanic field, southern New Mexico and northern Chihuahua, Mexico: New Mexico Geology, v. 4, no. 1, p. 6-8, 16.

*Griswold, G.B., 1961, Mineral deposits of Luna County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 72, 157 p.

*Griswold, G.B., Boy, R., Olson, R.R., and Zrinscak, P., 1989, Reconnaissance gold geochemical survey of five selected areas in southwestern New Mexico: New Mexico Bureau of Mines and Mineral Resources Open File Report OF-357, 19 p.

*Homme, F.C., 1958, Contact metamorphism in the Tres Hermanas Mountains, Luna County, New Mexico: Albuquerque, University of New Mexico, M.S. thesis, 88 p.

Homme, F.C., and Rosenzweig, A., 1970, Contact metamorphism in the Tres Hermanas Mountains, Luna County, New Mexico, *in* Woodward, L.A., ed., Guidebook of the Tyrone-Big Hatchet Mountains-Florida Mountains Region: New Mexico Geological Society, 21st Annual Field Conference, p. 141-145.

*Kottlowski, F.E., 1962, Reconnaissance of commercial high-calcium limestones in New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 60, 77p.

Kottlowski, F.E., and Foster, R.W., 1962, Pre-Tertiary strata of Tres Hermanas Mountains, Luna County, New Mexico: American Association of Petroleum Geologists Bulletin, v. 46, no. 11, p. 2090-2098.

*Kottlowski, F.E., Foster, R.W., and Wengerd, S.A., 1969, Key oil tests and stratigraphic sections in southwest New Mexico, *in* Cordoba, D.A., Wengerd, S.A., and Shomaker, J., eds., Guidebook of the Border Region; Chihuahua and the United States: New Mexico Geological Society, 20th Annual Field Conference, p. 186-196.

Leonard, M.L., 1982, The geology of the Tres Hermanas Mountains, Luna County, New Mexico: El Paso, University of Texas, unpublished M.S. thesis, 105 p.

Lindgren, W., 1909, The Tres Hermanas mining district, New Mexico: U.S. Geological Survey

Bulletin 380, p. 123-128.

*Lindgren, W., Graton, L.C., and Gordon, C.H., 1910, The ore deposits of New Mexico: U.S. Geological Survey Professional Paper 68, 361 p.

Seager, W.R., and Clemons, R.E., 1988, Geology of Hermanas quadrangle, Luna County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Geologic Map 63, scale 1:24,000.

Wade, W.R., 1913, Minerals of the Tres Hermanas district: Engineering and Mining Journal, v. 96, p. 589-590.

VICTORIO MOUNTAINS

by

V.T. McLemore

The west-northwest-trending, north-dipping, Victorio Mountains in west-central Luna County consist of Paleozoic and Cretaceous rocks (mostly limestone units) that have been intruded by porphyry and capped by volcanic rocks (**figure 4-3.7**). The range, which lies near the Deming axis, is on the southwestern edge of the Florida uplift. The range is cut by only a few faults. One of the faults, theVictorio Mountains fault, is an east-trending, southward–dipping fault or fault zone that has been interpreted most recently to be a strike-slip or polyphase normal fault (Thorman and Drewes, 1980)[earlier interpreted as a reverse fault (Kottlowski, 1960) and a thrust fault (Corbett and Woodward, 1970)]. The type of faulting in the Victorio Mountains remains poorly constrained. Folded sedimentary rocks are present locally.

Precambrian granitic rock is inferred to underlie the range, and the Bliss Formation underlies the area at shallow depth (Thorman and Drewes, 1980). Paleozoic rocks mapped in the Victorio Mountains include the El Paso Limestone, Montoya Group (Upham Dolomite, Cable Canyon Sandstone, Aleman Dolomite, and Cutter Dolomite, and Fusselman Dolomite (including from oldest to youngest the gray member, lower black member, tan member, and upper black member) (Kottlowski, 1960; Thorman and Drewes, 1980). These rocks are unconformably overlain by Bisbee(?) Group. Conglomerate, sandstone, siltstone, shale, and tuff breccia of Paleocene or Upper Cretaceous age unconformably overlies Mesozoic and Paleozoic rock. Combined thickness of these younger units ranges from 180 m to 250 m. Tertiary (Miocene?)volcanic and volcaniclastic rocks about 601 m thick cap the range.

A 2-m-thick rhyolite ash-flow tuff is interbedded within the volcanic rocks in the northwestern part of the Victorio Mountains. The age of this tuff unit was determined using fission-track methods to be 42 Ma (Thorman and Drewes, 1980). Volcanic and volcaniclastic rocks at the surface are intruded by rhyolite and rhyolite porphyry dikes, plugs, and sills. In

drilling, Gulf Minerals Resources encountered quartz latite porphyry and andesite sills and granite and rhyolite dikes and stocks. K/Ar chronologic age dates on granite, ash-flow tuff, and rhyolite porphyry are determined to be 32 Ma, 35 Ma, and 36 Ma, respectively (A.R. Bell, written commun., August 1983). A fission-track age from a rhyolite dike is reported as 25 Ma (Thorman and Drewes, 1980).

Mineral Resources

The Victorio mining district occurs in the Victorio Mountains (see McLemore and Sutphin, this volume).

References

(* reference used in writing above summary)

*Bell, A.R., 1983, Victorio Mountain molybdenum/tungsten project, Luna County, New Mexico: Gulf Mineral Resources Co., unpublished report on file at the Anaconda Geological Document Collection, American Heritage Center, University of Wyoming, No. 43303.01, 150 p.

*Corbitt, L.L., and Woodward, L.A., 1970, Thrust faults of the Florida Mountains, New Mexico, and their regional tectonic significance, *in* Woodward, L.A., ed., Guidebook of the Tyrone-Big Hatchet Mountains-Florida Mountains Region: New Mexico Geological Society, 21st Annual Field Conference, p. 69-74.

*Dale, V.B., and McKinney, W.A., 1959, Tungsten deposits of New Mexico: U.S. Bureau of Mines Report of Investigations 5517, 72 p.

*Drewes, Harald, 1989a, Description and development of the Cordilleran orogenic belt in the southwestern United States and northern Mexico: U.S. Geological Survey Professional Paper 1512, 92 p.

*Drewes, Harald, 1989b, Development of the foreland zone of the Cordilleran orogenic belt near the U.S.-Mexican Border, *in* Schmidt, C.J., and Perry, W.J., Jr., eds., Interaction of the Rocky Mountain Foreland and the Cordilleran thrust belt: Geological Society of America Memoir 171, p. 447-463.

*Drewes, Harald, 1991b, Description and development of the Cordilleran orogenic belt in the Southwestern United States and northern Mexico: U.S. Geological Survey Professional Paper 1512, 92 p.

*Griswold, G.B., 1961, Mineral deposits of Luna County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 72, 157 p.

*Griswold, G.B., Boy, R., Olson, R.R., and Zrinscak, P., 1989, Reconnaissance gold geochemical survey of five selected areas in southwestern New Mexico: New Mexico

Bureau of Mines and Mineral Resources Open File Report OF-357, 19 p.

*Hobbs, S.W, 1965, Tungsten, *in* Mineral and water resources of New Mexico: U.S. Congress, 89th, 1st session, Senate Committee on Interior and Insular Affairs: New Mexico Bureau of Mines and Mineral Resources Bulletin 87, p. 241-255.

*Holser, W.T., 1953, Beryllium minerals in the Victorio Mountains, Luna County, New Mexico: American Mineralogist, v. 38, p. 599-611.

*Jones, F.A., 1904, New Mexico mines and minerals: Santa Fe, The New Mexico Printing Company, p. 73-80.

*Kottlowski, F.E., 1960b, Summary of Pennsylvanian sections in southwest New Mexico and southeast Arizona: New Mexico Bureau of Mines and Mineral Resources Bulletin 66, 187 p.

*Kottlowski, F.E., Foster, R.W., and Wengerd, S.A., 1969, Key oil tests and stratigraphic sections in southwest New Mexico, *in* Cordoba, D.A., Wengerd, S.A., and Shomaker, J., eds., Guidebook of the Border Region; Chihuahua and the United States: New Mexico Geological Society, 20th Annual Field Conference, p. 186-196.

*Lindgren, W., Graton, L.C., and Gordon, C.H., 1910, The ore deposits of New Mexico: U.S. Geological Survey Professional Paper 68, 361 p.

Lynn, G.C., 1975, Stratigraphic correlation of the El Paso and Montoya Groups in the Victorio Mountains, the Snake Hille, and the Big Florida Mountains in southwestern New Mexico: Tucson, University of Arizona, unpublished Master's thesis, 115 p.

*North, R.M., and McLemore, V.T., 1986, Silver and gold occurrences in New Mexico: New Mexico Bureau of Mines and Mineral Resources Resource Map 15, 32 p., scale 1:1,000,000.

*Richter, D.H., and Lawrence, V.A., 1983, Mineral deposit map of the Silver City 1°x2° quadrangle, New Mexico and Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map I-1310-B, 70 p., scale 1:250,000.

*Thorman, C.H., and Drewes, H., 1980, Geologic map of the Victorio Mountains, Luna County, southwestern New Mexico: U.S. Geological Survey, Miscellaneous Field Studies Map MF-1175, scale 1:24,000.

*Turner, G.L., 1962, The Deming axis, southeastern Arizona, New Mexico, and Trans-Pecos Texas, *in* Weber, R.H., and Pierce, H.W., eds., Mogollon Rim Region (east-central Arizona): New Mexico Geological Society Guidebook, 13th Annual Field Conference, p. 59-71.

*Warner, L.A., Holser, W.T., Wilmarth, V.R., and Cameron, E.N., 1959, Occurrence of

nonpegmatite beryllium in the United States: U.S. Geological Survey Professional Paper 318, 198 p.

Woodward, L.A., 1970, Precambrian rocks of southwestern New Mexico, *in* Woodward, L.A., ed., Guidebook of the Tyrone-Big Hatchet Mountains-Florida Mountains Region: New Mexico Geological Society, 21st Annual Field Conference, p. 27-31.

Woodward, L.A., 1980, A hard look at overthrust belt prospects in southwest New Mexico: Oil and Gas Journal, v. 78, no. 16, p. 114-116.

Woodward, L.A., and DuChene, H.R., 1981, Overthrust belt of southwestern New Mexico--Comparison with Wyoming-Utah overthrust belt: American Association of Petroleum Geologists Bulletin, v. 65, no. 4, p. 722-727.

DOÑA ANA COUNTY

Doña Ana County forms the eastern boundary of the Mimbres Resource Area and includes the city of Las Cruces. Las Cruces (Spanish for "The Crosses"), got its name from a collection of crosses marking the burial ground of settlers killed by Native Americans in the 1840s. Las Cruces lies on El Camino Real, the major trading route from Mexico to Santa Fe along the Rio Grande. El Paso, Texas, and Juarez, Mexico, with a combined population of nearly 2 million, have a significant impact on the economy of Doña Ana County.

BISHOP CAP

Bishop Cap, southwest of the southern Organ Mountains uplift in eastern Doña Ana County, lies within the Organ caldera (**figure 1-6**).

General Geology

Over 915 m of Ordovician to Pennsylvanian rocks are exposed at Bishop Cap; these include the El Paso Limestone, Montoya Group, Fusselman Dolomite, Canutillo Formation, Percha Shale, Caballero Formation, Lake Valley Limestone, Rancheria Formation, Helms Formation, and the La Tuna and Berino Formations of the Magdalena Group. Subsurface units include Precambrian rocks, parts of the El Paso Limestone, Magdalena Group, and Hueco Group.

Five west-tilted fault blocks comprise Bishop Cap (**figure 4-4.1**). They are north- to northwest- trending and are cut by numerous north- to northwest-–trending and east and east-northeast–trending, high-angle faults. In the westernmost fault block, strata are folded into a broad monocline. Widespread Pleistocene to Recent deposits, including the Camp Rice Formation, surround the Bishop Cap hills. These relatively unconsolidated to weakly indurated deposits are estimated to be at least 92 m thick.

Mineral Resources

Fluorite and barite have been extracted from Bishop Cap. Deposits occur in fractured limestone and dolomite as open-space fillings, with minor replacements near faults, fractures, and in certain bedding zones. Mineralized areas are identified by silicification, and include shallow, resistant zones of jasper, chalcedony, and some opal. Ordovician and Silurian rocks are most susceptible to mineralization, but the Rancheria Formation is also locally altered and mineralized.

References

(* reference used in writing above summary)

El Foul, D., 1976, Stratigraphy and microfacies analysis of the Bishop Cap Formation at Vinton Canyon, Franklin Mountains, El Paso County, Texas, *in* LeMone, D.V., and Lovejoy, E.M.P., eds., El Paso Geological Society symposium on the Franklin Mountains: p. 57-60.

Flih, B., 1976, Osagian bioherms at the Bishop Cap hills, Doña Ana County, New Mexico: El Paso, University of Texas, M.S. thesis, 106 p.

Flih, Baghdad, 1976, Stratigraphy and preliminary microfacies studies of the Osage (Mississippian) bioherms of the Lake Valley Formation, Bishop Cap Hills, Doña Ana County, New Mexico, *in* LeMone, D.V., and Lovejoy, E.M.P., Symposium on the Franklin Mountains: El Paso Geological Society Quinn Memorial Volume, p. 35-44.

Kramer, W.V., 1970, Geology of the Bishop Cap hills, Doña Ana County, New Mexico: El Paso, University of Texas, unpublished Master's thesis, 76 p.

LeMone, D.V., and Flih, Baghdad, 1982, Waulsortian mounds of the Bishop Cap hills, Doña Ana County, New Mexico [abs.]: New Mexico Geology, v. 4, no. 1, p. 14.

*Seager, W.R., 1973, Geologic map and sections of Bishop Cap-Organ Mountains Area, New Mexico: New Mexico Bureau of Mines and Mineral Resources Geologic Map 29, scale 1:24,000.

CEDAR HILLS

Cedar Hills are located north of the Rough and Ready Hills in northwestern Doña Ana County.

General Geology

Cedar Hills form the eastern side of the Good Sight-Cedar Hills depression, also known as the Sierra de las Uvas ash-flow field (**figure 4-3.4**). The Cedar Hills include the Cedar Hills vent zone (Seager, 1975), which is composed of 27 rhyolite domes, andesite dikes, a buried cone, two Uvas Andesite vents, a diatreme, and a large collapsed area (Clemons, 1976). TheCedar Hills contain poorly exposed Precambrian and Paleozoic rocks and Cretaceous rocks; however, the major portion of the hills are made up of Tertiary volcanic and volcaniclastic deposits that may record the transition from post-Laramide events to Basin and Range tectonism along the Rio Grande Rift.

The northwest-trending Cedar Hills fault block is bounded by northwest-trending faults. The rocks are cut by the Late Tertiary Cedar Hills fault, which is structural control on the east side of the Good Sight-Cedar Hills depression. The first episode of fault movement took place about 26 m.y. ago, followed by movement 9 m.y. ago and in Pliocene time (Seager and others, 1975). The fault may represent initial movement in the Rio Grande Rift (Seager, 1975). Cinder cones and vents of the Uvas Andesite lie along the fault, and flows from it interfinger with fanglomerates that contain 26–m.y.-old rhyolite clasts.

Volcanic and volcaniclastic deposits of the Palm Park Formation, Bell Top Formation, and Uvas Andesite are overlain by the Rincon Valley Formation. Uvas Andesite deposition is thickest

near the axis of the Cedar Hills depresion and is related to Rio Grande Rift (Seager and Clemons, 1975). Late Tertiary and Pleistocene units in the Cedar Hills represent the latest stage in aggradation of late Tertiary fault basins. Sediments are piedmont-slope facies of the Santa Fe Group, including fans, pediment veneers, older slope, fluvial, and younger slope deposits with caliche caps. Late Pleistocene to Holocene valley and piedmont-slope alluvium and windblown deposits are present as arroyo, fan, and terrace deposits. Three major episodes of incision by the Rio Grande and its tributaries are followed by intervals of partial filling and stability (Seager and others, 1975). (See also Rio Grande Valley, this section)

Mineral Resources

Caliche and onyx deposits occur in near-surface Tertiary and Quaternary deposits (**figure 4-4.2**). Sand, gravel, and clay are plentiful, especially in the Camp Rice Formation and younger deposits.

References

(* reference used in writing above summary)

*Clemons, R.E., 1976, Geology of east half Corralitos Ranch quadrangle, New Mexico: New Mexico Bureau of Mines and Mineral Resources Geologic Map 36, scale 1:24,000.

*Clemons, R.E., 1976, Sierra de las Uvas ash-flow field, south-central New Mexico, *in* Woodward, L.A., and Northrop, S.A., Tectonics and mineral resources of southwestern North America: New Mexico Geological Society Special Publication 6, p. 115-121.

Clemons, R.E., and Seager, W.R., 1973b, Cenozoic geology of the Goodsight-Cedar Hills volcanic-tectonic depression, *in* Hoffer, J.M., ed., The geology of southcentral Dona Ana County, New Mexico: El Paso Geological Society, 7th Annual Fieldguide, p. 50-55.

Hawley, J.W., Seager, W.R., and Clemons, R.E., 1975, Third Day road log from Las Cruces to north Mesilla Valley, Cedar Hills, San Diego Mountain, and Rincon area, *in* Seager, W.R., Clemons, R.E., and Callender, J.F., eds., Las Cruces Country: New Mexico Geological Society 26th field conference guidebook, p. 35-53.

Seager, W.R., 1975, Cenozoic tectonic evolution of the Las Cruces area, New Mexico, *in* Seager, W.R., Clemons, R.E., and Callender, J.F., eds., Guidebook of the Las Cruces Country: New Mexico Geological Society, 26th Annual Field Conference, p. 241-250.

*Seager, W.R., and Clemons, R.E., 1975, Middle to late Tertiary geology of Cedar Hills-Selden Hills area, New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 133, 24 p.

*Seager, W.R., Clemons, R.E., and Hawley, J.W., 1975, Geology of Sierra Alta quadrangle, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 102, 56 p.

Seager, W.R., Clemons, R.E., Hawley, J.W., and Kelley, R.E., 1982, Geology of northwest part of Las Cruces 1˚x2˚ sheet, New Mexico: New Mexico Bureau of Mines and Mineral Resources Geologic Map 53, scale 1:125,000.

Varnell, R., 1976, Geology of the Hat Top Quadrangle, Luna County, New Mexico: El Paso, University of Texas, unpublished M.S. thesis, 62 p.

CERRO DE CRISTO REY (EL CERRO DE MULEROS)

Cerro de Cristo Rey is located west of El Paso at the boundary between the U.S. and Mexico, and the states of Texas and New Mexico (T. 29 S., R. 3-4 E.). The hill reaches an altitude of 1,421 m, about 305 m above the La Mesa surface.

General Geology

Cerro de Cristo Rey is located at the junction of the southern Rio Grande Rift, the northern edge of the Laramide orogenic belt, and the extension of the Texas lineament (**figure 4-4.3**). It is an andesite-cored hill about 3,050 m in diameter having an adjacent felsite sill or pluton on the southwest, and numerous faults. Cerro de Cristo Rey is nearly bisected by the Mexico-U.S. boundary west of El Paso. The structure, which has been described as a laccolith, may be a pluton (Lovejoy, 1976). This asymmetrical pluton and associated structures in the region, and a pluton 1-2 km to the southeast (the Campus andesite pluton of Hoffer, 1969), are aligned in a northwest trend paralleling the trend of the Texas lineament. Dikes, sills, and plugs are probably a comagmatic series of intrusives (based on geochemical data) that may have evolved from a single, large, underlying caldera or pluton. Cerro de Cristo Rey uplift, which possibly took place during Basin-and-Range deformation, has been deeply eroded, exposing the andesite core.

Cretaceous rocks that extend from the Franklin Mountains to Cerro de Cristo Rey have been intruded by andesite and felsite and dip away from the uplift. Small-scale folds, some overturned, are exposed on the northeast and east side of the mountain. Cretaceous rocks are cut by 47–m.y.–old andesite east of Cerro de Cristo Rey. The age is significant because it represents the only magmatic event of that age in the region.

Cretaceous sedimentary rocks include (from base to top) the Courchesne Formation (equivalent to Finlay Limestone), Del Norte Formation including the Brick Plant Member (lower clay member) and the Refinery Member (equivalent to upper calcareous member), the Smeltertown Formation, Muleros Formation, Mesilla Valley Formation, Anapra Formation, Del Rio Formation, Buda Limestone, and the Boquillas Formation (Strain, 1968a; Lovejoy, 1976).

The andesite pluton lies within the Rio Grande Rift and Basin-and-Range provinces, and the Trans-Pecos magmatic belt (Hoover and others, 1988). The Rio Grande has cut the eastern portion of the intrusive.

Mineral and Energy Resources

A basal white limestone is quarried from the Early Cretaceous limey-clay and marly limestone-bearing units that total 26 m in thickness east of the Cerro de Cristo Rey (Kottlowski, 1962). They contain 93.3 percent calcium carbonate (nearly high-calcium limestone), but they are interbedded with shaly and sandy beds. Clay and silica quarries in Cretaceous rocks have provided materials for local use in the manufacture of bricks and as copper-smelter flux, respectively.

Intrusion of middle Eocene andesite and felsite into Cretaceous rocks increased the geothermal gradient. Thermal maturation studies by Norland (1985) show that hydrocarbon generation could occur within the Mesilla Valley Shale, and that the formation may be oil-prone.

References

(* reference used in writing above summary)

Böse, E., 1906, Excursion au Cerro de Muleros, International Geological Congress 10, Guide Exc. 20, 24 p.

Böse, E., 1910, Monografia geologia y paleontologia del Cerro de Muleros; Bol. del Instituto Geologicao de Mexico, no. 25, 193 p.

Cornell, W.C., and LeMone, D.V., 1987, The Anapra Sandstone of Cerro de Cristo Rey, Doña Ana County, New Mexico: New Mexico Journal of Science, v. 27, p. 123.

*Hoffer, J.M., 1969, Geology and petrography of the Campus Andesite pluton, El Paso County, Texas, *in* Cordoba, D.A., Wengerd, S.A., and Shomaker, J., eds., Guidebook of the Border Region; Chihuahua and the United States: New Mexico Geological Society, 20th Annual Field Conference, p. 102-107.

*Hoover, J.D., Ensenat, S.E., Barnes, C.G., and Dyer, R., 1988, Early trans-Pecos magmatism-- Petrology and geochemistry of Eocene intrusive rocks in the El Paso area, *in* Mack, F.H., Lawton, T.F., and Lucas, S.G., eds., Cretaceous and Laramide tectonic evolution of southwestern New Mexico: Guidebook, New Mexico Geological Society, 39th Annual Field Conference, p. 109-118.

Kennedy, W.J., Cobban, W.A., and Hook, S.C., 1988, Middle Cenomanian (Late Cretaceous) molluscan fauna from the base of the Boquillas Formation, Cerro de Muleros, Dona Ana County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin, v. 114, p. 35-44.

*Lovejoy, E.M.P., 1976, Geology of Cerro de Cristo Rey Uplift, Chihuahua and New Mexico: New Mexico Bureau of Mines and Mineral Resources Memoir 31, p. 84.

Lovejoy, E.M.P., 1972, La estructura y tectonica intrusive del Cerro de Cristo Rey, Chihuahua,

Mexico y Nuevo Mexico, Estados Unidos: Geological Society of Mexico, Convencion Nacionale, Memoir no. 2, p. 170-172.

Nodeland, S., and Cornell, W.C., 1976, Microfossils of the Smeltertown Formation stratotype (Cretaceous, Albian), Mount Cristo Rey, New Mexico, *in* LeMone, D.V., and Lovejoy, E.M.P., eds., El Paso Geological Society Symposium on the Franklin Mountains: p. 87-89.

*Norland, W.D., 1985, Thermal maturation of the Mesilla Valley Formation (Late Albian) on the north and east flanks of the Cerro de Cristo Rey pluton, Doña Ana County, New Mexico: New Mexico Geology, v. 7, no. 3., p. 64.

*Small, T.A., 1958, El Cerro de Muleros (Cerro Cristo del Rey), New Mexico and Mexico, *in* Nelson, L.A., and Haigh, B.R., leaders, Franklin and Hueco Mountains, Texas: West Texas Geological Society Fieldtrip Guidebook, p. 68-69.

Strain, W.S., 1976, New formation names in the Cretaceous at Cerro de Cristo Rey, Doña Ana County, New Mexico, *in* Lovejoy, E.M., Geology of Cerro de Cristo Rey Uplift, Chihuahua and New Mexico: New Mexico Bureau of Mines and Mineral Resources Memoir 31, p. 77-82.

DOÑA ANA MOUNTAINS

Doña Ana Mountains are located northwest of Las Cruces in Doña Ana County. They are a northwest-trending mountain range at the southwestern edge of the Jornada del Muerto basin (**figure 4-4.4**).

General Geology

The westward-tilted Doña Ana Mountains are part of an uplifted block within the Rio Grande Rift area. Geologic units consist of Permian- to Quaternary-age sedimentary, plutonic, and volcanic rocks (**figure 4-4.5**). The oldest units exposed in the northern part of the range include Hueco Group rocks, including possible Bursum Formation beds, that grade into Abo Formation redbeds, marking the Permian shelf edge. Both units are folded and faulted and form basinal deposits along the margin of the Orogrande basin to the southeast. Bursum Formation(?) (lowermost Hueco) is exposed at Grande dome in the northern part of the range.

Paleozoic rocks are intruded by andesite and monzonite that are part of middle Tertiary (Eocene) post-Laramide volcanic and tectonic episodes. Eocene rocks include the Palm Park Formation, Cleofas Andesite, and Love Ranch Formation.

In the southern part of the range, a deeply eroded, partially exposed, Oligocene caldera, the Doña Ana caldera (part of the Organ caldera of McIntosh and others, 1992), is a southeastern extension of the Mogollon-Datil volcanic field. Doña Ana caldera is about 8-13 km in diameter.

Seager and others (1976) estimate that 763 m of ash–flow tuff initiated caldera collapse, and that about 305 m of rhyolite flows and domes, tuffs, volcaniclastic deposits, and breccia comprise younger caldera fill in the Doña Ana caldera. Mapped units of Oligocene age include Doña Ana rhyolite (the initial emanation from the Doña Ana caldera) and unnamed breccias, flows, tuffs, and plutonic monzonitic and mafic plutonic rocks. Ash-flow tuff and monzonite porphyry are 34 m.y. and 35 m.y., respectively (K-Ar; Seager and others, 1976; NMBMMR files). Dikes related to a ring fracture system radiate from the caldera margin to the north, and a smaller caldera (Dagger Flat caldera) and graben (Red Hills graben) occur within the main caldera. Uplift and erosion of the Doña Ana caldera exposes 915 m of the edifice beneath the Oligocene surface.

Late Tertiary faulting raised the range into a west-tilted horst. Jornada and Valley faults are inferred on geophysical maps to occur on the northeast and southwest, respectively (Seager and others, 1976). Basalt and basalt porphyry dikes and plugs occur that are middle to late Miocene in age and are related to rifting.

Quaternary and Tertiary units on the flanks of the mountain range, including the Camp Rice Formation, are mainly unconsolidated fan and pediment deposits. These units have been eroded and dissected as a result of tectonism along the Rio Grande Rift.

References

(* reference used in writing above summary)

Hawley, J.W., and Kottlowski, F.E., 1965, Road log from Las Cruces to Nutt, *in* Fitzsimmons, J.P., and Lochman-Balk, Christina, eds., 1965, Guidebook of southwestern New Mexico II: New Mexico Geological Society, 16th Field Conference, p. 15-27.

Kottlowski, F.E., 1960, Reconnaissance geologic map of Las Cruces thirty-minute quadrangle: New Mexico Bureau of Mines and Mineral Resources Geologic Map 14, scale 1:126,720.

Mack, G.H., James, W.C., and Seager, W.R., 1988, Wolfcampian stratigraphy and depositional environments in the Doña Ana Mountains, south-central New Mexico, *in* Basin to shelf facies transition of the Wolfcampian stratigraphy of the Orogrande Basin: Permian Basin Section, Society of Economic Paleontologists and Mineralogists Publication 88-28, p. 97-106.

*McIntosh, W.C., Chapin, C.E., Ratté, J.C., and Sutter, J.F., 1992, Time-stratigraphic framework for the Eocene-Oligocene Mogollon-Datil volcanic field, southwest New Mexico: Geological Society of America Bulletin, v. 104, p. 851-871.

*Seager, W.R., 1975, Cenozoic tectonic evolution of the Las Cruces area, New Mexico, *in* Seager, W.R., Clemons, R.E., and Callender, J.F., eds., Guidebook of the Las Cruces Country: New Mexico Geological Society Guidebook, 26th Field Conference, p. 241-250.

*Seager, W.R., 1975, Geologic map and sections of South Half San Diego Mountain Quadrangle, New Mexico: New Mexico Bureau of Mines and Mineral Resources Geologic Map 35, scale 1:24,000.

*Seager, W.R., 1981, Geology of the Organ Mountains and southern San Andres Mountains, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Memoir 36, 97 p.

*Seager, W.R., Kottlowski, F.E., and Hawley, J.W., 1976, Geology of Doña Ana Mountains, Doña Ana County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Circular 147, 36 p.

EAST POTRILLO MOUNTAINS

(See also Afton and Aden Craters area and West Potrillo Mountains)

East Potrillo Mountains are located in southern Doña Ana County along the border with Mexico.

General Geology

East Potrillo Mountains have undergone tectonic deformation during all three tectonic episodes—during late Cretaceous and early Tertiary time (Laramide) in early to middle Tertiary time (post-Laramide), and late Tertiary time (Basin and Range). During initiation of the Rio Grande Rift, before extrusion of Quaternary basalt, the area of the West and East Potrillo Mountains was faulted. A north-south-trending block separates the two mountain ranges and comprises the intervening valley (Seager, 1987).

The northwest-trending uplifted fault block that comprises the East Potrillo Mountains forms a narrow outcrop belt composed of folded and faulted Lower Cretaceous deposits composed of alternating clastics and carbonates with a total thickness of about 534 m (**figure 4-4.6**). These rocks are disconformably underlain by Lower Permian limestone and dolomite (Hueco Group?). Structural features are more complex to the northwest, but these rocks, although locally silicified in one fault block, are typically unmetamorphosed. The northern part of the range is cut by numerous faults that trend northwest and northeast. The central part of the range is composed of weakly metamorphosed Cretaceous rocks that have a northeast-trending lineation and a slight cleavage; two sets of oblique faults cut the central range. Homoclinal sequences in the southwestern part of the range dip to the southwest. Porphyritic andesite dikes, probably Tertiary in age, trend northeasterly, cutting the bedded sequences. Dikes cut the overturned folds and thrusts of Laramide age, but are faulted by high-angle faults that are probably related to Basin-and-Range activity. The southern part of the range is structurally relatively undisturbed, and composed of a simple monocline truncated by a high-angle fault on the east.

Mt. Riley (1,804 m) and Mt. Cox, two peaks from a single felsic pluton that was emplaced

during early to middle Tertiary time, intrude dense trachydacite of probable Tertiary age, Cretaceous(?) sedimentary rocks, and Tertiary volcanic and sedimentary rocks. The peaks are northwest extensions of the East Potrillo range.

Tertiary and Quaternary deposits cover the flanks of the East Potrillo Mountains, consisting of poorly sorted, coarse, caliche-cemented bajada deposits of fanglomerate and talus. Deposits terminate at a 3-8-ft-high fault escarpment (similar to other escarpments in the region) that extends northward on the east side of the mountains.

References

(* reference used in writing above summary)

Anthony, E.Y., Barnes, C.G., Chen, W., Hoffer, J.M., Keller, G.R., Marsaglia, K.M., McLemore, V.T., Seeley, J.M., Seward, M.A., Shannon, W.M., and Thomann, W.F., 1991, Examples of modern rift volcanism and Proterozoic anorogenic magmatism--The Potrillo volcanic field of southern New Mexico and the Franklin Mountains of west Texas, *in* Julian, Betsy, and Zidek, Jiri, Field guide to geologic excursions in New Mexico and adjacent areas of Texas and Colorado: New Mexico Bureau of Mines and Mineral Resources Bulletin 137, p. 1-19.

Aubele, J.C., Crumpler, L. S., Loeber, K.N., and Kudo, A.M., 1976, Maare and tuff rings of New Mexico, *in* Woodward, L.A., and Northrop, S.A., eds., Tectonics and mineral resources of southwestern North America: New Mexico Geological Society Special Publication No. 6, p. 109-114.

*Bowers, W.E., 1960, Geology of the East Potrillo Hills, Doña Ana County, New Mexico: University of New Mexico, unpublished Master's thesis, 67 p.

Craig, R., 1972, Stratigraphic correlation of the East Potrillo Mountains with Sierra de Juarez; The Stratigraphy and structure of Sierra de Juarez, Chihuahua, Mexico: El Paso Geological Society Annual Field Trip, Guidebook 6, p. 17-18.

Heylmun, E.B., 1986, East Potrillo Mountains, New Mexico: California Mining Journal, v. 55, no. 5, p. 10-12.

Hoffer, J.M., 1969b, Volcanic history of the Black Mountain-Santo Tomas basalts, Potrillo volcanics, Doña Ana County, New Mexico, *in* Cordoba, D.A., Wengerd, S.A., and Shomaker, J., eds., Guidebook of the Border Region; Chihuahua and the United States: New Mexico Geological Society, 20th Annual Field Conference, p. 108-114.

Hoffer, J.M., 1971, Mineralogy and petrology of the Santo Tomas-Black Mountain basalt field, Potrillo volcanics, south-central New Mexico: Geological Society of America Bulletin, v. 82, p. 603-612.

*Hoffer, J.M., 1976a, Geology of Potrillo Basalt Field, south-central New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 149, 30 p.

Hoffer, J.M., 1976b, The Potrillo Basalt Field, south-central New Mexico: New Mexico Bureau of Mines and Mineral Resources Special Publication 5, p. 89-92.

Hoffer, J.M., Chen, W., McLemore, V.T., and Anthony, E.Y., 1991, Day 2--The Potrillo volcanic field, *in* Julian, Betsy, and Zidek, Jiri, Field guide to geologic excursions in New Mexico and adjacent areas of Texas and Colorado: New Mexico Bureau of Mines and Mineral Resources Bulletin 137, p. 12-19.

Hoffer, J.M., and Hoffer, R.L., 1981a, A note on Lower Cretaceous outcrops, southeastern Luna County, New Mexico, *in* Hoffer, J.M., and Hoffer, R.L., eds., Geology of the border; southern New Mexico-northern Chihuahua: El Paso Geological Society Guidebook, p. 54-56.

*Hoffer, J.M., and Hoffer, R.L., 1981b, Geology of the East Potrillo Mountains, southern Doña Ana County, New Mexico, *in* Hoffer, J.M., and Hoffer, R.L., eds., Geology of the border; southern New Mexico-northern Chihuahua: El Paso Geological Society Guidebook, p. 57-61.

*James, H.L., and McCall, W.B, 1965, Exit roadlog from Lordsburg to Las Cruces, *in* Fitzsimmons, J.P., and Lochman-Balk, Christina, eds., Guidebook of southwestern New Mexico II: New Mexico Geological Society, 16th Field Conference, p. 86-92.

Jenkins, D.A., 1977, Geologic evaluation of the EPM mining claims, East Potrillo Mountains, Doña Ana County, New Mexico: Socorro, New Mexico Institute of Mining and Technology, unpublished Master's thesis, 109 p.

*Kahn, P.A., 1987, Geology of Aden Crater, Doña Ana County, New Mexico: El Paso, University of Texas, unpublished M.S. thesis, 90 p.

*Kottlowski, F.E., Foster, R.W., and Wengerd, S.A., 1969, Key oil tests and stratigraphic sections in southwest New Mexico, *in* Cordoba, D.A., Wengerd, S.A., and Shomaker, J., eds., Guidebook of the Border Region; Chihuahua and the United States: New Mexico Geological Society, 20th Annual Field Conference, p. 186-196.

Mack, G.H., 1986, Lower Cretaceous stratigraphy and depositional environments in the East Potrillo Mountains and adjacent areas of southwestern New Mexico, *in* Hoffer, J.M., ed., Geology of southcentral New Mexico: El Paso Geological Society Guidebook, p. 85-94.

Pickens, C.A., 1983, An Early Cretaceous rudist biostrome sequence in East Potrillo Mountains, Doña Ana County, New Mexico [abs.]: New Mexico Geology, v. 5, no. 3, p. 64.

Powell, D.L., 1983, Stratigraphic nomenclature of East Potrillo Mountains, Doña Ana County,

New Mexico [abs.]: New Mexico Geology, v. 5, no. 3, p. 64.

Reeves, C.C., Jr., and DeHon, R.A., 1965, Geology of Potrillo Maar, New Mexico and northern Chihuahua, Mexico: American Journal of Science, v. 63, p. 401-409.

Renault, Jacques, 1970, Major-element variations in the Potrillo, Carrizozo, and McCartys basalt fields, New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 113, 22 p.

Seager, W.R., and Mack, G.H., 1986, Summary of geology of East Potrillo Mountains area: El Paso Geological Society, Guidebook, p. 158-159.

Seager, W.R., and Mack, G.H., 1994, Geology of East Potrillo Mountains and vicinity, Doña Ana County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 113, 27 p.

Snyder, J.T., 1986, Heat flow in the southern Mesilla basin with an analysis of the East Potrillo geothermal system: Las Cruces, New Mexico State University, unpublished Master's thesis, 252 p.

Wasilewski, P.J., and Padovani, E.R., 1981, Crustal magnetization beneath the Rio Grande Rift based on xenoliths from Kilbourne Hole and Potrillo Maar--Papers presented to the Conference on the processes of planetary rifting: Lunar and Planetary Institute Contribution 457, p. 153-155.

FRANKLIN MOUNTAINS (NORTHERN PART, NEW MEXICO)

Franklin Mountains lie north and east of El Paso and southeast of Las Cruces. The northern part of the north-south–trending mountain range forms a westward-tilted fault block, with a steep eastern escarpment, that extends to about 16 km north of the New Mexico-Texas boundary.

General Geology

The Franklin Mountains are an uplifted, basement-cored block in which Middle Proterozoic rocks have been subdivided and dated. Late Cambrian to Quaternary sedimentary sequences rest on Precambrian sedimentary, metamorphic, and granitic rocks (in the subsurface in New Mexico, but exposed just south of the Texas state line). To the south in Texas, the thickest sequences (about 2,044 m thick) of the oldest Precambrian terrane are exposed, and are intruded by younger Precambrian granite complexes.

Precambrian exposed rocks in the Franklin Mountains, as described mainly by Harbour (1960), include, from oldest to youngest, Castner Limestone (locally metamorphosed), Mundy Breccia, Llanoria Quartzite, and the Thunderbird Group [consisting of conglomerate, rhyolite lavas, and trachyte ignimbrites (pyroclastic rocks composed of pumice and glass shards)], all intruded by Red Bluff Granite [1.1 billion years old, and probably formed in a rift environment

(Thomann, 1991)] (Shannon and Barnes, 1991). All of these Precambrian units are intruded by Precambrian(?) diabase dikes. Basement sequences are overlain disconformably and unconformably by Bliss Formation, El Paso Limestone, Montoya Group, Fusselman Dolomite, Canutillo Formation and Percha Shale, Las Cruces, Rancheria, and Helms Formations, La Tuna, Berino, and Bishop Cap Formations, the Panther Seep Formation and the Hueco Group. No Mesozoic rocks are present in the northern Franklin Mountains, although they are present in Texas. Late Tertiary to Quaternary deposits unconformably overlie Paleozoic rocks, and include the Camp Rice Formation fluvial, eolian deposits, and piedmont slope deposits. Holocene deposits include valley-slope, fluvial, arroyo, fan, and dune deposits. Tertiary and Quaternary deposits have been locally modified and affected by activity on the Rio Grande Rift.

The Franklin Mountains, structurally complex in detail, are faulted on the east and west by normal faults of Basin and Range type; these are the East Boundary fault zone and the West Boundary fault zone. Clint fault, a normal fault located west of the Franklin Mountains near El Paso, Tex., nearly parallels the Rio Grande Valley; it is reported from oil well penetration data to have normal stratigraphic offset of 3,050 m, down to the southwest. Clint fault has been linked to the northwest-trending Texas lineament, and a splay of the fault may be the Mesilla Valley fault located 3-6 mi west of the Franklin Mountains in New Mexico. There are a series of faults on the west side of the Franklin Mountains; the entire system may be part of a zone of basement-rooted features that developed on the edge of the craton. Further to the south, southeast of El Paso and the Franklin Mountains, the northwest-trending Rio Grande thrust fault (largely concealed) separates deformed terrane on the southwest from undeformed terrane to the northeast; it may be the frontal fault of the Cordilleran orogenic belt of Drewes (1981).

References

(* reference used in writing above summary)

Anthony, E.Y., Barnes, C.G., Chen, W., Hoffer, J.M., Keller, G.R., Marsaglia, K.M., McLemore, V.T., Seeley, J.M., Seward, M.A., Shannon, W.M., and Thomann, W.F., 1991, Examples of modern rift volcanism and Proterozoic anorogenic magmatism--The Potrillo volcanic field of southern New Mexico and the Franklin Mountains of west Texas, *in* Julian, Betsy, and Zidek, Jiri, Field guide to geologic excursions in New Mexico and adjacent areas of Texas and Colorado: New Mexico Bureau of Mines and Mineral Resources Bulletin 137, p. 1-19.

Barrie, F., 1976, A Bouguer gravity anomaly map of the Franklin Mountains, New Mexico and Texas, *in* Corbitt, L.L., ed., Geology of the Florida Mountains, Luna County New Mexico: El Paso Geological Society, Guidebook 8, p. 161-163.

Cathey, Carl, Hoenig, Margaret, Oden, James, and Rubio, Jesus, 1976, Magnetic survey of east side of Campus Pluton, *in* LeMone, D.V., and Lovejoy, E.M.P., Symposium on the Franklin Mountains: El Paso Geological Society, Quinn Memorial Volume, p. 165-176.

Cathey, Carl, Hoenig, Margaret, Oden, James, and Rubio, Jesus, 1976, Magnetic resolution of the Three Sisters--Preliminary report, *in* LeMone, D.V., and Lovejoy, E.M.P., eds., Symposium on the Franklin Mountains: El Paso Geological Society, Quinn Memorial Volume, p. 177-180.

Cooley, B., 1958, Oil exploration in the area of the Franklin and Hueco Mountains: West Texas Geological Society Guidebook, 1958 Field Trip, p. 70-72.

Deen, R.D., 1976, The mineralization in the Precambrian rocks of the Northern Franklin Mountains, *in* LeMone, D.V., and Lovejoy, E.M.P., eds., Symposium on the Franklin Mountains: El Paso Geological Society Quinn Memorial Volume, p. 183-188.

Denison, R.E., and Hetherington, E.A., 1969, Basement rocks in far west Texas and south-central New Mexico, *in* Kottlowski, F.E., and LeMone, D.V., eds., Border Stratigraphy Symposium: New Mexico Bureau of Mines and Mineral Resources Circular 104, p. 1-16.

El Foul, D., 1976, Stratigraphy and microfacies analysis of the Bishop Cap Formation at Vinton Canyon, Franklin Mountains, El Paso County, Texas, *in* LeMone, D.V., and Lovejoy, E.M.P., eds., Symposium on the Franklin Mountains: El Paso Geological Society, p. 57-60.

Goodell, P.C., 1976, Mineral occurrences of the Franklin Mountains, Texas; in LeMone, D.V. and Lovejoy, E.M.P., eds., Symposium on the Franklin Mountains: El Paso Geological Society, Quinn Memorial Volume, p. 189-200.

Goodell, P.C., 1987, Mineral occurrences of the Franklin Mountains, Texas, in LeMone, D.V., and Lovejoy, E.M.P., El Paso Geological Society symposium on the Franklin Mountains: El Paso Geological Society no. 10, Quinn volume, , p. 189-200.

Hair, G.L., 1976, The Upper Pennsylvania Panther Seep Formation (Virgilian) of the Franklin Mountains, Doña Ana County, New Mexico, and El Paso County, Texas, *in* LeMone, D.V., and Lovejoy, E.M.P., eds., Symposium on the Franklin Mountains: El Paso Geological Society, p. 61-66.

Hair, G.L., 1976, Stratigraphy and microfacies analysis of Panther Seep Formation (Virgilian), Franklin Mountains, Texas, New Mexico: El Paso, University of Texas, unpublished Master's thesis, 70 p.

Harbour, R.L., 1960, Road log from las Cruces to Vinton Canyon and Anthony

Gap--Pennsylvanian localities in the northern Franklin Mountains: Roswell Geological Society Guidebook, Northern Franklin Mountains and southern San Andres Mountains, p. 11-33.

*Harbour, R.L., 1972, Geology of the northern Franklin Mountains, Texas and New Mexico: U.S. Geological Survey Bulletin 1298, 129 p.

*Kelley, Shari, and Matheny, J.P., 1983, Geology of Anthony quadrangle, Luna County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Geologic Map 54, scale 1:24,000.

Kondelin, R.J., and LeMone, D.V., 1983, Ordovician rocks of Webb Gap area, north Franklins, Doña Ana County, New Mexico [abs.]: New Mexico Geology, v. 5, no. 3, p. 63.

Kottlowski, F.E., 1958a, Geologic history of the Rio Grande near El Paso, *in* Nelson, L.A. and Haigh, B.R., leaders, Franklin and Hueco Mountains, Texas: West Texas Geological Society 1958 Fieldtrip Guidebook, p. 46-54.

Kottlowski, F.E., 1960c, Depositional features of the Pennsylvanian of south-central New Mexico: Roswell Geological Society Guidebook, Northern Franklin Mountains and southern San Andres Mountains, p. 96-130.

LeMone, D.V., 1976, General stratigraphy of the Franklin Mountains, *in* LeMone, D.V., and Lovejoy, E.M.P., eds., Symposium on the Franklin Mountains: El Paso Geological Society, p. 1-3.

*LeMone, D.V., 1989, Geology of the Franklin Mountains, Texas, *in* Drewes, Harald, and Dyer, Russ, 1989, Tectonics of the eastern part of the Cordilleran Orogenic Belt, Chihuahua, New Mexico, and Arizona, Field Trip Guidebook T121, 28th International Geological Congress: American Geophysical Union, Washington, D.C., p. 8-11.

Lovejoy, E.M.P., 1975, An interpretation of the structural geology of the Franklin Mountains, Texas, *in* Seager, W.R., Clemons, R.E., and Callender, J.F., eds., Guidebook of the Las Cruces Country: New Mexico Geological Society, 26th Annual Field Conference, p. 261-268.

Lovejoy, E.M.P., 1976b, A little problem concerning Fort Hancock-Camp Rice "mixed rounded gravels"; correlation in the El Paso-Las Cruces regions, as viewed by a skeptic, *in* LeMone, D.V., and Lovejoy, E.M.P., eds., Symposium on the Franklin Mountains: El Paso Geological Society Quinn Memorial Volume, p. 99-104.

Lovejoy, E.M.P., and Seager, W.R., 1978, Discussion of structural geology of Franklin Mountains: New Mexico Bureau of Mines and Mineral Resources Circular 163, p. 68-69.

Madden, H.D., and LeMone, D.V., 1983, Stratigraphy and regional relationships of Mississippian

system north Franklin Mountains, Doña Ana County, south-central New Mexico [abs.]: New Mexico Geology, v. 5, no. 3, p. 64.

McEvers, Lloyd, and LeMone, D.V., 1983, Fusselman Dolomite of north Franklin Mountains, Doña Ana County, New Mexico [abs.]: New Mexico Geology, v. 5, no. 3, p. 64.

Million, D.T., 1986, Microfacies analysis and depositional environment comparison of two sections of Ordovician El Paso Formation, southern Franklin Mountains, west Texas, and northern Big Hatchet Mountains, southwest New Mexico [abs.]: New Mexico Geology, v. 8, no. 3, p. 68-69.

*Nelson, L.A., 1940, Paleozoic stratigraphy of the Franklin Mountains, west Texas: American Association of Petroleum Geologists Bulletin, v. 24, p. 157-172.

Nelson, L.A., and Haigh, B.R., leaders, 1958, Franklin and Hueco Mountains, Texas: West Texas Geological Society, 1958 Fieldtrip Guidebook, p. 46-54.

Pray, L.C., 1958, Stratigraphic section, Montoya Group and Fusselman Formation, Franklin Mountains, Texas: West Texas Geological Society, Guidebook, 1958, p. 30-42.

Pyron, A.J., 1980, Geology and geochemistry of the El Paso tin deposits, Franklin Mountains, El Paso County, Texas: El Paso, University of Texas, unpublished Master's thesis, unknown p.

Richardson, G.B., 1904, Report of a reconnaissance in Trans-Pecos Texas, north of the Texas and Pacific Railway: Texas University Mineral Survey, Bulletin 9, 119 p.

Richardson, G.B., 1906, Tin in the northern Franklin Mountains, Texas: U.S. Geological Survey Bulletin 285-C, p. 146-149.

Richardson, G.B., 1908, Paleozoic formations in Trans-Pecos Texas: American Journal of Science, v. 25, p. 474-484.

Roark, R.C., LeMone, D.V., and Von Finger, Kevin, 1983, Stratigraphy of Pennsylvanian System, north Franklin Mountains, Doña Ana County, New Mexico [abs.]: New Mexico Geology, v. 5, no. 3, p. 64.

Setra, A., 1976, Stratigraphy and microfacies analyses of the Mississippian Las Cruces Formation (Osage– Meramec), Vinton Canyon, El Paso County, Texas, *in* LeMone, D.V., and Lovejoy, E.M.P., Symposium on the Franklin Mountains: El Paso Geological Society, p. 45–49.

Shannon, W.M., and Barnes, C.G., 1991, Summary of the geochemistry and petrology of Proterozoic granitic rocks, Franklin Mountains, west Texas, *in* Julian, Betsy, and Zidek, Jiri, Field guide to geologic excursions in New Mexico and adjacent areas of Texas and Colorado: New Mexico Bureau of Mines and Mineral Resources Bulletin 137, p. 7-12.

Simpson, R.D., and LeMone, D., 1982, Permian brachiopods from the Alacran Mountain Formation, Franklin Mountains, Texas and New Mexico [abs.]: New Mexico Geology, v. 4, no. 1, p. 13.

Simpson, R.D., 1984, Permian Brachiopoda from far West Texas and southwestern New Mexico: University of Texas at El Paso, unpublished Ph. D. dissertation, 429 p.

Thomman, W.F., 1981, Ignimbrites, trachytes, and sedimentary rocks of the Precambrian Thunderbird Group, Franklin Mountains, El Paso, Texas: Geological Society of America Bulletin, v. 92, no. 2, p. 94-100.

Thomman, W.F., 1991, Petrology of the middle Proterozoic Thunderbird Group, Franklin Mountains, El Paso, Texas, *in* Julian, Betsy, and Zidek, Jiri, Field guide to geologic excursions in New Mexico and adjacent areas of Texas and Colorado: New Mexico Bureau of Mines and Mineral Resources Bulletin 137, p. 5-7.

JORNADA DEL MUERTO

The broad central plain of the Jornada del Muerto (the La Mesa geomorphic surface of Ruhe, 1964; see Rio Grande section) extends to the north from Las Cruces to beyond the Doña Ana County line, and from the western San Andres Mountains to the Rio Grande.

General Geology

Jornada del Muerto lies about 153 m above the Rio Grande and contains many closed depressions that are aligned; the elevation change between the lowest and highest points ranges from 23 m to 31 m (**figure 4-4.7**). Younger Picacho terrace level lies closer to the river and about 122 m below the Jornada del Muerto terrace.

Near Las Cruces, Tertiary and Quaternary beds on and beneath the Jornada surface contain reddish clay, gypsum, interbedded breccia tuffs, latitic tuffs, latite-andesite breccias and flows, welded rhyolite tuffs, Bell Top Formation units, flows of Uvas basalt, units of the Santa Fe Group, fossil-bearing, locally caliche-cemented, Pleistocene beds, and Recent fluvial gravels and sands in terraces and flood plain deposits. Well data shows that the southern Jornada del Muerto basin is more than 305 m thick. Goat Mountain, a rhyolite dome, is located at the southwestern edge of the basin.

On the piedmont slope of the Organ-San Andres mountain chain, the Jornada del Muerto is a broad, coalescent alluvial-fan surface sloping toward the basin. South of the Point of Rocks (the southern Jornada del Muerto), the broad piedmont appears to be aggradational, in places modified by tectonic warping, eolian activity, and possible subsidence due to deep-solution removal of gypsum.

Mineral Resources

As much as 31 m of carbonate- and silica-cemented Santa Fe Group deposits occur on the Rincon surface (near Rincon Hills); the upper 15 m are typically caliche caprock. Sand and gravel deposits are thick and widespread, as are materials for manufacture of adobe brick. Ground water is produced (as much as 500-1,500 gpm) from the Jornada del Muerto from wells more that 305 m deep in Santa Fe Group deposits.

References

(* reference used in writing above summary)

Bisdorf, R.J., 1985, Schlumberger sounding results in the Hueco Bolson, New Mexico: U.S. Geological Survey Open-File Report 85-0607, 120 p.

Decker, E.R., Cook, F.A., Ramberg, I.B., and Smithson, S.B., 1975, Significance of geothermal and gravity studies in the Las Cruces area, *in* Seager, W.R., Clemons, R.E., and Callender, J.F., eds., Guidebook of the Las Cruces Country: New Mexico Geological Society, 26th Annual Field Conference, p. 251-259.

Decker, E.R., and Smithson, S.B., 1975, Heat flow and gravity interpretation in southern New Mexico and West Texas: Journal of Geophysical Research, v. 80, p. 2542-2552.

Doty, G.C., and Cooper, J.B., 1970, Stratigraphic test well T-14, Post area, White Sands Missile Range, New Mexico: U.S. Geological Survey Open-File Report, 34 p.

Gile, L.H., Hawley, J.W., and Grossman, R.B., 1981, Soils and geomorphology in the Basin and Range area of southern New Mexico--guidebook to the Desert Project: New Mexico Bureau of Mines and Mineral Resources Memoir 39, 222 p.

*Hawley, J.W., and Kottlowski, F.E., 1965, Road log from Las Cruces to Nutt, *in* Fitzsimmons, J.P., and Lochman-Balk, Christina, eds., 1965, Guidebook of southwestern New Mexico II: New Mexico Geological Society, Sixteenth Field Conference, p. 15-27.

Keyes, C.R., 1905, Geology and underground water conditions of the Jornada del Muerto: U.S. Geological Survey Water-Supply Paper 123, 42 p.

*King, W.E., Hawley, J.W., Taylor, A.M., and Wilson, R.P., 1971, Geology and ground-water resources of central and western Doña Ana County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Hydrologic Report 1, 64 p.

Kottlowski, F.E., 1953, Road log from Las Cruces to Silver City, *in* Kottlowski, F.E., ed., Southwestern New Mexico: New Mexico Geological Society Guidebook, 4th Annual Field Conference, p. 29-41.

*Kottlowski, F.E., 1953, Tertiary-Quaternary sediments of the Rio Grande valley in southern New Mexico, *in* Kottlowski, F.E., ed., Southwestern New Mexico: New Mexico

Geological Society Guidebook, 4th Annual Field Conference, p. 144-147.

Kottlowski, F.E., 1953, Road log, Alamogordo to Deming, New Mexico, along US-70: Roswell Geological Society, Guidebook 11th Field Conference, p. 99-116.

Neal, J.T., 1976, Pleistocene Lake Trinity, a sulfate basin in the northern Jornada del Muerto, New Mexico: Abstracts of the Fourth biennial meeting of the American Quaternary Association; American Quaternary Association National Conference Abstracts, v. 4, p. 155.

Reinke, R.E., 1978, Surface wave propagation in the Tularosa and Jornada del Muerto basins, south-central New Mexico: Southern Methodist University, unpublished Ph. D. dissertation.

Reiter, M., and Barroll, M.W., 1990, High heat flow in the Jornada del Muerto; a region of crustal thinning in the Rio Grande Rift without upper crustal extension, *in* Luccitta, I., and Morgan, P., eds., Heat and detachment in continental extension: Tectonophysics, v. 174, nos. 1-2, p. 183-195.

*Seager, W.R., and Hawley, J.W., 1973, Geology of Rincon quadrangle, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 101, 42 p., map scale 1:24,000.

Stickel, Roseann, 1988, Preliminary work on the determination of groundwater flow using chemical analysis, Jornada del Muerto Basin, Doña Ana County, New Mexico [abs.]: New Mexico Geology, v. 10, no. 3, p. 66.

Templain, C.J., and Dotterrer, R.E., 1978, Preliminary study of the uranium favorability of the Hornada del Muerto Basin and adjacent areas, south-central New Mexico: GJBX 80-78, 22 p.

West, A.M., Lawton, T.F., Mack, G.H., and Clemons, R.E., 1993, Subsurface stratigraphy of Pennsylvanian strata beneath the Jornada del Muerto, south-central New Mexico [abs.]: Proceedings, New Mexico Geological Society Annual Spring Meeting, Socorro, p. 71.

ORGAN-SAN ANDRES MOUNTAINS

Organ and San Andres Mountains form a north-south, west-tilted, mountain chain along the north- and east-central Doña Ana County line (**figure 4-4.8**). The northern and central San Andres Mountains lie north of the Mimbres Resource Area. The northern Franklin Mountains are a southern extension of the chain within the study area. Within the study area, all of the San Andres Mountains and most of the Organ Mountains are within the White Sands Missile Range and adjoining Fort Bliss Military Reservation, White Sands National Monument, and various Wilderness and National Wildlife Refuge lands (**figure 1-2**), making access difficult and the area off-limits to mining, oil and gas drilling, and exploration.

General Geology

Organ-San Andres Mountains have a gentle western slope and a steeply faulted eastern escarpment. The northern and central San Andres Mountains are built up mainly of Paleozoic rock underlain by Precambrian granite (**figure 4-4.9**). The southern San Andres-Organ Mountains are composed of Paleozoic rocks that have been uplifted and intruded by the quartz monzonite stock of the Organ batholith and associated intrusive and extrusive rocks. Although the eastern side of the Organ-San Andres mountain chain has the greatest amount of uplift and exposure (abut 1,373 m of relief over 4.8 km), in the vicinity of the Organ batholith, the eastern escarpment is more gently dipping than the rugged masses of intrusive and extrusive rocks exposed on the abrupt and scarp-like, western side. On the west side of the Organ Mountains, exposed intrusive rocks of quartz syenite and quartz-alkali feldspar syenite of the Organ batholith erode in such a way as to resemble organ pipes (known as the Needles). The latest and most comprehensive works in the southern San Andres-Organ Mountains are by Seager (1981) and Kottlowski and LeMone (1994), and it is mostly from these works that the following synthesis is derived.

Stratigraphy

Precambrian basement rocks (mostly granite) are exposed in the lowermost east-central foothills of the Organ Mountains; in the San Andres Mountains, Precambrian rocks are exposed north of Rhodes Canyon (Sierra County) on the lower parts of the eastern slope (Kottlowski, 1955, 1959; Kottlowski and others, 1956; Budding and Condie, 1975). Precambrian rocks are mostly metamorphosed (schists, quartzites, and amphibolites) and are intruded by granitic rocks. The Precambrian granitic-metamorphic complex was later intruded by diorite-diabase dikes in northeast– trending fractures. The dikes are younger than the Precambrian granitic-metamorphic complex but do not cut the Cambrian and Ordovician Bliss Formation. Near the Stevenson-Bennett mine on the west side of the Organ Mountains, a large block of Precambrian granitic-metamorphic rock with diorite-amphibolite dikes is interpreted as a roof pendant in the much younger (Tertiary/Oligocene) Organ batholith. At the end of Precambrian time, a period of erosion resulted in a regional Precambrian pediment surface onto which Paleozoic marine sediments were deposited (**figure 4-4.10**).

Paleozoic rocks are about 1,434 m thick, but are faulted and partly metamorphosed adjacent to younger intrusive and volcanic rocks. Paleozoic rocks include the Bliss Formation, El Paso Limestone, Montoya Group, Fusselman Dolomite, Canutillo Formation, Percha Shale, Lake Valley Limestone, undifferentiated Pennsylvanian limestones, and the Hueco Group. Generally, the units are thinned by Laramide uplift and erosion.

Bliss Formation, an easily recognized dark band that grades into the overlying El Paso

Limestone, thins northward from the Franklin Mountains to a pinch-out in the Oscura Mountains (**appendix B**). El Paso Limestone thins northward, and is absent in parts of the Oscura Mountains. Montoya Group lies disconformably on the El Paso as a result of uplift, southward tilting, and erosion of pre-Montoya rocks. Fusselman Dolomite is recognized in the southern Organ Mountains where it is sharply unconformable on the Montoya Group as a result of renewed uplift, southward tilting, and erosion of pre-Fusselman beds. It is unconformable with overlying Devonian rocks, and pinches out in the southern San Andres Mountains at Bear Canyon.

A regional unconformity in Early Devonian time, resulting from renewed uplift and southward tilting, extends from the Franklin Mountains to the Oscura Mountains and truncates Cambrian and Ordovician through Middle Silurian strata (Kottlowski and others, 1956). Devonian Canutillo Formation and Percha Shale thin northward from the Franklin Mountains to the southern San Andres Mountains (Bear Canyon area); Canutillo beds grade upward into the poorly exposed Percha Shale. Percha Shale is commonly distorted and highly variable in thicknessesas a result of bedding plane and thrust faulting; it apparently thins northward, and is locally removed and infilled with Mississippian strata. Due to their impermeability, the Devonian shale units may have trapped circulating mineralizing solutions and been responsible for deposition of ore minerals near the Fusselman Dolomite and Devonian contact.

Mississippian strata include, from base to top, the Caballero, Lake Valley Limestone, Las Cruces, Rancheria, and Helms Formations; the strata are probably disconformable on the underlying units. Only at Bishop Cap and Rattlesnake Ridge (southern Organ Mountains) are all units exposed. In Late Mississippian time the seas retreated to as far as the El Paso, Tex., area, and Mississippian strata were exposed and eroded; the strata were subsequently buried by northward transgressive Pennsylvanian marine deposits. Pennsylvanian units include the Lead Camp Limestone, La Tuna Formation, Berino Formation, and Panther Seep Formation. There are no major unconformities within the Pennsylvanian sequence, which generally record a cyclic depositional record of near-shore marine environments, with occasional influx in early to middle Pennsylvanian time of coarse terrigenous deposits derived from the Pedernal uplift to the northeast. Pennsylvanian rocks overlie Precambrian rocks in the range north of the study area.

In Late Pennsylvanian time, a subsiding basin, the Orogrande Basin, developed by downwarping adjacent to the Pedernal uplift, into which deltaic and intertidal Pennsylvanian deposits (Panther Seep Formation) were deposited. In earliest Permian time, cyclic marine strata (Hueco Group limestone in the Organ Mountains and the Bursum Formation further north) were deposited into the subsiding Orogrande Basin. Hueco Group limestone occurs north of the thrust and fold zone near Bear Peak (southern San Andres Mountains). On the west side of the Organ

Mountains, Hueco rocks are overlain by lower Tertiary volcanic rocks and conglomerate. Later in Early Permian time, fluvial clastics were deposited over much of central New Mexico owing to uplift in the Colorado Plateau region. Terrestrial deposits of the Abo Formation encroached southward into the Orogrande Basin area contemporaneous with deposition of the Hueco rocks. Continental Abo deposits are, thus, transitional into the marine Hueco deposits (their contact marks the shoreline). In the Organ, southern San Andres, and Robledo Mountains, the shoreline shifted back and forth, resulting in intertonguing of the two formations in those areas. By middle Permian time, the sea transgressed northward and lagoonal and shallow water sediments and evaporites of the Yeso and San Andres Formations were deposited north of the study area.

Triassic, Jurassic, and early Cretaceous deposits are missing from the Organ-southern San Andres Mountains, probably due to later uplift and erosion along the Rio Grande uplift. However, north of the Bear Peak fold and thrust zone, remnants of nearshore marine and beach deposits of the latest Early Cretaceous Sarten-Dakota Sandstones and Mancos Shale are present, and represent a northward marine transgression. Final regression is recorded in the Late Cretaceous rocks (coarser grained nearshore and beach facies). All evidence of subsequent Upper Cretaceous deposition has been removed by erosion.

Unconformably overlying the Paleozoic and Mesozoic rocks are the Love Ranch Formation conglomerate and red beds, and Tertiary rhyolitic to andesitic tuffs and flows (Orejon Andesite). These units represent orogenic deposits of the Laramide and later events (basin formation, block faulting, and westward tilting). In the vicinity of the Organ Mountains, volcanic activity apparently took place during Eocene to Miocene time (when there was andesitic volcanism and associated plutonism) and culminated in Oligocene time (predominantly an epoch of silicic volcanism and related plutonism)(Seager, 1981).

In the Love Ranch area (southern San Andres Mountains), as much as 610 m of the Love Ranch Formation, a late Laramide deposit, overlies older Paleozoic and Mesozoic rocks (Love Ranch basin; **figure 1-5**); the formation thins along the edges of the uplifted blocks in the western and southern Organ Mountains. In the Stevenson-Bennett area and Modoc mines area, the Love Ranch Formation is only a meter or so thick above Hueco Group-Abo Formation beds, and in the southern Organ Mountains, it overlies Pennsylvanian rocks. Love Ranch Formation is part of the Bear Peak fold and thrust zone (see below).

Love Ranch Formation is locally overlain by a thin unit that may be the McRae Formation in the Love Ranch area (Kelley and Silver, 1952; Bushnell, 1953, 1955). The McRae(?) contains probable Precambrian granitic clasts, indicating that Precambrian rocks were exposed and recycled by erosion in Tertiary time.

Post-Laramide volcanic rocks buried Laramide deposits and structures in the Organ–southern San Andres Mountains area, and were intruded by the Organ batholith. Structural trend of these later features are oblique to Laramide features, having a north-south trend.

Organ Batholith

Organ batholith forms the peaks of the central Organ Mountains and the San Agustin Pass area, and covers about 130 km^2. The batholith was intruded into Precambrian rocks that comprise the core of a Laramide uplift; the Organ Mountains were uplifted by the intrusion of the pluton, and tilted to the west. Organ batholith underlies probably contemporaneous, and possibly co-magmatic, tuffs (**figure 4-4.11**). Escape of volcanic ejecta whose source was the underlying magma of the batholith was from a caldera or from several calderas (the Organ caldera complex described below). Due to subsequent erosion and (or) burial by gravel deposits, direct evidence for the presence of the calderas is equivocal, and is based primarily on the thickness and attitude of overlying tuffs. A 3-km thickness of volcanic debris was deposited within the caldera (Cueva Rhyolite, Soledad Rhyolite, and West Side lavas were deposited as moat and ring-fracture deposits). The margin of the Organ caldera is described as a southwest-dipping, hinged caldera (Seager, 1981; McIntosh and others, 1992).

Radiometric dating of the Organ batholith reveal that it is Oligocene. The batholith is more mafic than the overlying silicic volcanic units, averaging about 60-65 percent SiO_2. It results from multiple intrusions of varying composition and is termed a composite batholith; the two main plutons that make up the batholith are the Sugarloaf Peak pluton [dated as 34 m.y. by McLemore and others (1995)] and the older Organ Needle pluton. Some stoping by the batholith (melting and assimilation of the intruded country rock into the magma) took place during intrusion as indicated by the presence of scattered xenoliths (blocks) of Precambrian rock, lower Paleozoic strata, and upper Eocene andesite within the quartz monzonite stock. Metamorphic effects of the batholith are evident in an aureole up to 1.5 km wide along the northern and western margins of the batholith.

Along the north and east margins, the batholith is typically discordant with bedded wallrocks and with Paleozoic and Precambrian rocks, suggesting that the batholith is steep-sided. North of the Modoc mines area, the batholith is overlain by Paleozoic rocks and the Love Ranch Formation. Along its western margin, the contact is bounded by a series of steeply dipping faults, or has partially concordant relations with Paleozoic strata. In other areas, it may be subconcordant with surrounding strata, especially with overlying volcanic rocks --it apparently has a semiconcordant roof. Organ batholith may be a portion of an underlying, more extensive batholith (Seager, 1981). Portions of the batholith are younger than the overlying volcanic units, and it is likely that the magma remaining in the main chamber after eruption of the volcanic portion is what

comprises the batholith.

Calderas

The late Eocene or early Oligocene Orejon Andesite forms the roof of, as well as roof pendants within, the Organ batholith that intrudes it. The middle Oligocene rocks are mostly rhyolitic, and are thought to be co-magmatic with the Organ batholith. Volcanic tuffs and flows, separated by clastic rocks, are up to 3,050 m thick and form an insulating cap. All of these units are termed the Organ caldera complex.

In the Organ Mountains [the southern part of the Organ caldera of McIntosh and others, (1992), and the Organ caldera of Seager (1981)], the Cueva Rhyolite (Dunham, 1935) grades upward into the tuff of Cox Ranch (Seager, 1981) and both units form the basal tuff of the Organ complex (and are the units included in the Soledad Rhyolite). These basal units are described as initial eruptive units forming the Organ caldera. They are overlain by a series of unnamed porphyritic lava flows that are at least 305 m thick (tops are covered by gravel) and that range in composition from rhyolite to trachyte. These flows form the final stage in the volcanic episode, but they are probably co-magmatic and nearly contemporaneous with the underlying tuffs. They probably represent a more viscous magma that flowed from the vent after the initial, more explosive eruption of the gas-charged tuffs. Roof pendants of volcanic rock in the upper part of the batholith are relatively undeformed, suggesting that the tuffs and flows subsided into the collapsing and cooling magma chamber of the batholith (Seager, 1981).

Doña Ana caldera, the northern portion of the Organ caldera of McIntosh and others (1992), comprises most of the southern Doña Ana Mountains and includes an ash-flow tuff called the Doña Ana rhyolite, which is 763 m thick, as well as associated rhyolitic to monzonitic intrusives (**figure 4-4.5**). K/Ar dating of rocks in the region shows them to be about 33-37 m.y. old. Boundaries of the caldera are marked by flow-banded rhyolite, monzonite porphyry and other intrusives, and by localized occurrences of pre-caldera rocks. The caldera is 8-13 km in diameter and may include a second, smaller caldera, named the Dagger Flat caldera. The Doña Ana caldera is deeply eroded, and Seager (1975) estimates that the deposits now exposed represent the internal fabric of the caldera to a depth of 915 m below the original surface of the volcano.

East of the southern Organ Mountains in the Black Hills, mafic, ultra-potassic lava up to 153 m thick has been extruded above the rhyolitic flows and tuffs. Flows with interbeds of conglomerate (up to 31 m thick) have been downfaulted and tilted to the east. Owing to the structural relations of the flows and conglomerates, it is suggested (Chapin and Seager, 1975) that the units represent an early stage of extension on the Rio Grande Rift, in which the lava flows were extruded to the surface from relatively shallow reservoirs. Fan deposits and pediments

(represented by the conglomerates) were deposited off of rising mountain ranges flanking the basins, washing over the lava flows and becoming interbedded with them. The sequence is covered by Pleistocene deposits of sand and gravel.

Faults and Folds

Fault zones are typically branching systems of faults that are generally north-trending and have dip-slip offsets; the attitude is controversial in the subsurface. Overall structure of the southern San Andres Mountains is that of a faulted arch that is probably related to downdropping of the adjacent basins. Older fault systems in the San Andres Mountains cut the Laramide Bear Peak fold and thrust belt and displace monzonite dikes related to the Organ batholith.

Systems of closely spaced faults that pre-date range-front fault systems are present in uplifted areas of south-central New Mexico, and are interpreted to have formed during uplift events and the early stages of rifting. Subsequent to these faults, a series of range-front or boundary faults were formed. Neither are dated radiometrically, and age determinations in the Organ-San Andres Mountains area are deciphered from truncation relations, style of deformation, and spatial relation with dikes and sills thought to be related to intrusion of the Organ batholith (Seager, 1981).

Laramide structures

Within the Organ and southern San Andres Mountains, the Bear Peak thrust and Torpedo–Bennett fault zone, and possibly the Black Prince fault, are major structural features associated with block uplift in Laramide time. West-northwest-trending Bear Peak thrust and fold belt is the northern boundary of Laramide block uplift in the southern San Andres Mountains, wherein a block of Precambrian and Paleozoic rocks on the south are raised along a series of reverse faults. On the north (downthrown) side of the thrust and fold zone, an overturned syncline whose axis parallels the reverse fault zone is present. Synclinal beds have been thinned, and minor faults occur locally that result from compaction of the folds.

Torpedo-Bennett fault zone includes high-angle, normal and reverse faults that flank the western edge of the Organ Mountains. The zone is interpreted as the western boundary of a Laramide block uplift. The fault zone separates uplifted Precambrian strata on the east from overturned to vertical synclinal Paleozoic strata west of the fault. Torpedo-Bennett fault zone is mineralized and intruded by the Organ batholith. Faulting predates intrusion of the batholith (33 m.y.), and is probably related to Laramide uplift events.

The north-trending, relatively complex, Black Prince fault zone parallels the Torpedo–Bennett fault zone and also late Tertiary faults in the area. It apparently does not offset the Bear Peak fault and fold belt, nor does it occur with certainty north of the belt. Age of faulting is

equivocal, but Seager (1981) postulates that it, too, is a Laramide feature.

Late Tertiary Fault Systems

Fault zones that are part of the younger fault system include the Organ Mountains fault zone and the Artillery Range fault zone on the east side of the range, and the West-side boundary fault (concealed) and Jornada fault (mostly concealed) on the west side of the range. These faults are part of a large system of range-front and boundary faults and splays that are exposed on the east side of the Franklin-Organ-San Andres Mountain range system from El Paso, Tex., to Mockingbird Gap, and that are mostly concealed by alluvium on the west side, from the Caballo Mountains to the southern Organ Mountains. Those on the east side have sharp escarpments as much as 24 m high that cut alluvial fans and pediment surfaces. All range to Quaternary in age, and some are thought to be Holocene (about 1,000 yr B.P.; Gile, 1986). Other suspected Late Tertiary systems include the north-trending normal faults that dissect the Bear Peak thrust and fold belt.

Mineral Resources

Uppermost Fusselman Dolomite is marked by prospects and mines, since this unit hosts many of the barite-fluorite and base-metal deposits.

References

(* reference used in writing above summary)

Albritton, C.C., and Nelson, V.E., 1943, Lead, zinc, and copper deposits of the Organ district, New Mexico (with a supplement on the occurrence of bismuth): U.S. Geological Survey Open-File Report 43, 39 p.

Alford, D.E., 1986, Origin of the Hembrillo succession of Proterozoic-age San Andres Mountains, south-central New Mexico [abs.]: New Mexico Geology, v. 8, no. 3, p. 68.

Alford, D.E., 1987, Geology and geochemistry of the Hembrillo Canyon succession, San Andres Mountains, Sierra and Doña Ana counties, New Mexico: Socorro, New Mexico Institute of Mining and Technology, unpublished M.S. thesis, 180 p.

Bachman, G.O., and Myers, D.A., 1969, Geology of the Bear Peak area, Doña Ana County, New Mexico: U.S. Geological Survey Bulletin 1271-C, 46 p.

Beehner, T.S., 1990, Burial of fault scarps along the Organ Mountains fault, south-central New Mexico: Association of Engineering Geologists Bulletin, v. 27, no. 1, p. 1-9.

*Beyer, J.B., McCurry, M., and Seager, W.R., 1985, A preliminary interpretation of some compositional and textural gradients across a mafic facies of the Organ Needle quartz monzonite, New Mexico: New Mexico Geology, v. 7, no. 3, p. 64.

Budding, A.J., and Condie, K.C., 1975, Precambrian rocks of the Sierra Oscura and northern

San Andres Mountains, *in* Seager, W.R., Clemons, R.E., and Callender, J.F., ed., Guidebook of the Las Cruces Country: New Mexico Geological Society, 26th Annual Field Conference, p. 89-93.

*Bushnell, H.P., 1953, Geology of the McRae Canyon area, Sierra County, New Mexico: University of New Mexico, unpublished Master's thesis, 106 p.

*Bushnell, H.P., 1955, Mesozoic stratigraphy of south-central New Mexico, *in* Fitzsimmons, J.P., ed., South-central New Mexico: New Mexico Geological Society, *in cooperation with* the Roswell Geological Society, 6th Annual Field Conference, p. 81-87.

*Chapin, C.E., and Seager, W.R., 1975, Evolution of the Rio Grande Rift in the Socorro and Las Cruces area, *in* Seager, W.R., Clemons, R.E., and Callender, J.F., ed., Guidebook of the Las Cruces Country: New Mexico Geological Society, 26th Annual Field Conference, p. 297-321.

Clauter, D.A., 1981, A paleomagnetic study of the Organ Mountain intrusive: Eos, Transactions, American Geophysical Union, v. 62, no. 45, p. 855.

Clemons, R.E., 1988, Lost Padre Mine--Fact or fiction? [abs.]: 9th Annual New Mexico Mineral Symposium, Proceedings, p. 7.

*Condie, K.C., and Budding, A.J., 1979, Geology and geochemistry of Precambrian rocks, central and south-central New Mexico: New Mexico Bureau of Mines and Mineral Resources Memoir 35, 58 p.

Cowan, Chris, 1994, Notable miarolitics of the Organ Mountains [abs.]: New Mexico Geology, v. 16, no. 1, p. 15.

Cruz, R.R., 1974, Annual water-resources review, White Sands Missile Range,1973; a basic data report: U.S. Geological Survey Open-File Report, 36 p.

Cruz, R.R., 1977, Annual water-resources review, White Sands Missile Range, 1976; a basic data report: U.S. Geological Survey Open-File Report 77-0330, 27 p.

Cruz, R.R., 1978, Annual water-resources review, White Sands Missile Range, New Mexico; 1977: U.S. Geological Survey Open-File Report 78-0553, 42 p.

Cruz, R.R., 1979, Annual water-resources review, White Sands Missile Range, New Mexico: U.S. Geological Survey Open-File Report 79-0985, 33 p.

Cruz, R.R., 1980, Annual water-resources review, White Sands Missile Range, New Mexico: U.S. Geological Survey Open-File Report 80-0753, 28 p.

Cruz, R.R., 1981, Annual water-resources review, White Sands Missile Range, New Mexico: U.S. Geological Survey Open-File Report 81-0921, 32 p.

Cruz, R.R., 1982, Annual water-resources review, White Sands Missile Range, New Mexico:

U.S. Geological Survey Open-File Report 82-0757, 24 p.

Cruz, R.R., 1983, Annual water-resources review, White Sands Missile Range, New Mexico: U.S. Geological Survey Open-File Report 83-0695, 20 p.

Cruz, R.R., 1984, Annual water-resources review, White Sands Missile Range, New Mexico, 1983: U.S. Geological Survey Open-File Report 84-0720, 40 p.

Cruz, R.R., 1985, Annual water-resources review, White Sands Missile Range, New Mexico, 1984: U.S. Geological Survey Open-File Report 85-0645, 25 p.

Delaney, T.A., 1987, Analytical results and sample locality map of heavy-mineral-concentrate and rock samples from the Organ Mountains Wilderness study area (NM-030-074), Doña Ana County, New Mexico: U.S. Geological Survey Open-File Report.

Doty, G.C., and Cooper, J.B., 1970, Stratigraphic test well T-14, Post area, White Sands Missile Range, New Mexico: U.S. Geological Survey Open-File Report, 34 p.

*Dunham, K.C., 1935, The geology of the Organ Mountains: New Mexico Bureau of Mines and Mineral Resources Bulletin 11, 272 p.

Eveleth, R.W., 1983, An historical vignette --Stephenson-Bennett mine: New Mexico Geology, v. 5, no. 1, p. 9-13, 15.

Fitzpatrick, D.P., McCurry, M., and Seager, W.R., 1988, The stratigraphy of the Cueva Tuff, part of a major intracaldera ash-flow tuff within the late Oligocene Organ Cauldron, southern New Mexico [abs.]: Geological Society of America Abstracts with Programs, v. 20, no. 3, p. 160.

Gile, L.H., 1987, Late Holocene displacement along the Organ Mountains fault in southern New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 196, 43 p.

Glover, T.J., 1975, Geology and ore deposits of the northwestern Organ Mountains, Doña Ana County, New Mexico: El Paso, University of Texas, M.S. thesis, 93 p.

Hammond, J., 1973, The Stephenson-Bennett Mine: The Mineralogical Record, v. 4, no. 1, p. 31-35.

Hammond, J., 1989, The Stephenson-Bennett Mine: The Mineralogical Record, v. 20, no. 1, p. 25-30.

Kelley, T.E., 1975, The Lost Padre Mine and the Organ mining district, *in* Seager, W.R., Clemons, R.E., and Callender, J.F., eds., Guidebook of the Las Cruces Country: New Mexico Geological Society, 26th Annual Field Conference Guidebook, p. 163-165.

Kottlowski, F.E., 1959, Sedimentary rocks of the San Andres Mountains: Roswell Geological Society and Permian Basin Section, Society of Economic Paleontologists and Mineralogists Guidebook, Sacramento Mountains, p. 259-277.

Kottlowski, F.E., 1962, Reconnaissance of commercial high-calcium limestones in New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 60, 77 p.

Kottlowski, F.E., 1966, The Lost Padre mine: New Mexico Magazine, October, p. 22-23, 34, 36.

Kottlowski, F.E., 1975, Stratigraphy of the San Andres Mountains in south central New Mexico, *in* Seager, W.R., Clemons, R.E., and Callender, J.F., eds., Guidebook of the Las Cruces Country: New Mexico Geological Society, 26th Annual Field Conference, p. 95-104.

*Kottlowski, F.E., Flower, R.H., Thompson, M.L., and Foster, R.W., 1956, Stratigraphic studies of the San Andres Mountains, New Mexico: New Mexico Bureau of Mines and Mineral Resources Memoir 1, 132 p.

*Kottlowski, F.E., and LeMone, D.V., 1994, San Andres Mountains stratigraphy revisited, *in* Garber, R.A., and Keller, D.R., eds., Field guide to the Paleozoic section of the San Andres Mountains: 1994 Annual Field Trip Guidebook, Permian Basin Section -SEPM, PBS-SEPM Publication No. 94-35, p. 31-45.

*Ludington, Steve, Hanna, W.R., Turner, R.L., and Jeske, R.E., 1988, Mineral resources of the Organ Mountains Wilderness Study Area, Doña Ana County, New Mexico: U.S. Geological Survey Bulletin 1735-D, p. D1-D17.

Macer, R.J., 1978, Fluid inclusion studies of fluorite around the Organ cauldron, Doña Ana County, New Mexico: El Paso, University of Texas, unpublished Master's thesis, 107 p.

*McIntosh, W.C., Chapin, C.E., Ratté, J.C., and Sutter, J.F., 1992, Time-stratigraphic framework for the Eocene-Oligocene Mogollon-Datil volcanic field, southwest New Mexico: Geological Society of America Bulletin, v. 104, p. 851-871.

Newcomer, R.W., Jr., and Giordano, T.H., 1986, Porphyry-type mineralization and alteration in the Organ mining district, south-central New Mexico: New Mexico Geology, v. 8, no. 4, p. 83-86.

Reiche, P. 1938, Recent fault scarps, Organ Mountain district, New Mexico: American Journal of Science, Series 5, v. 36, no. 216, p. 440-444.

*Seager, W.R., 1975, Cenozoic tectonic evolution of the Las Cruces area, *in* Seager, W.R., Clemons, R.E., and Callender, J.F., eds., Guidebook of the Las Cruces Country: New Mexico Geological Society, 26th Annual Field Conference, p. 241-250.

Seager, W.R., 1980, Quaternary-age fault system in the Tularosa and Hueco Basins, southern New Mexico and west Texas, *in* Dickerson, P.W., Hoffer, J.M., and Callender, J. F., eds., Trans Pecos region (west Texas): New Mexico Geological Society Guidebook, 31st Annual Field Conference, p. 131-136.

*Seager, W.R., 1981, Geology of the Organ Mountains and southern San Andres Mountains, New Mexico: New Mexico Bureau of Mines and Mineral Resources Memoir 36, 97 p.

Seager, W.R., and Brown, L.F., 1978, The Organ caldera, *in* C.E. Chapin and W.E. Elston, eds., Field guide to selected cauldrons and mining districts of the Datil-Mogollon volcanic field, New Mexico: New Mexico Geological Society, Special Publication 7, p. 139-149.

*Seager, W.R., and Clemons, R.E., 1989, Geology of the Las Cruces area, New Mexico, *in* Drewes, H., and Dyer, R., eds., Sedimentation and tectonics of western North America, volume 2--Tectonics of the eastern part of the Cordilleran orogenic belt, Chihuahua, New Mexico and Arizona: Washington, D.C., American Geophysical Union, p. 11-15.

Seager, W.R., and McCurry, M., 1988a, The cogenetic Organ cauldron and batholith, south central New Mexico--Evolution of a large-volume ash flow cauldron and its source magma chamber, *in* Tilling, R.E., ed., Special section on How Volcanoes Work; Part 2: Hawaii symposium; Journal of Geophysical Research, v. 93, no. 5, p. 4421-4433.

Seager, W.R., and McCurry, M., 1988, The Organ cauldron and cogenetic Organ batholith—Evolution of a large volume silicic magma chamber: Journal of Geophysical Research, May 10, 1988.

Soulé, J.H., 1951, Investigation of the Torpedo copper deposits--Organ mining district, Doña Ana County, New Mexico: U.S. Bureau of Mines Investigation Report 4791, 10 p.

VanDevender, T.R., and Everitt, B.L., 1977, The latest Pleistocene and Recent vegetation of the Bishop's Cap, south-central New Mexico: The Southwestern Naturalist, v. 22, no. 3, p. 337-352.

Welsh, N.J., 1914, The Organ mining district: Engineering and Mining Journal, v. 98, p. 331-334.

Yanicak, S.M., Seager, W.R., Giordano, T.H., and McCurry, M.O., 1992, Petrology of silicic and syenitic facies of the Organ Needle pluton, Organ Mountains batholith, Doña Ana County, southern New Mexico [abs.]: New Mexico Geological Society Proceedings Volume, 1992 Annual Spring Meeting, p. 21. [also New Mexico Geology, v. 14, no. 3, p. 63-64.]

POTRILLO AND SANTO TOMAS-BLACK MOUNTAIN BASALT FIELDS

(See also East Potrillo Mountains, West Potrillo Mountains sections)

General Geology

Maars and basalt flows occur west of the Rio Grande within the rift and the Basin and Range provinces, and on the La Mesa surface (see Rio Grande valley section). The lava ranges in age from Pleistocene to Recent (**figure 4-4.12**). Afton and Aden Craters area, Potrillo basalt

field, is located in southern Doña Ana County along the border with Mexico. East of Aden-Afton Craters area, four additional eruptive centers extend along the eastern margin of La Mesa surface; these include Santo Tomas, San Miguel, Little Black Mountain, and Black Mountain, collectively referred to as the Santo-Tomas-Black Mountain basalt field (Hoffer, 1969; 1971; 1976).

Basalts in the area, which are thought to have been derived from a small, shallow (less than 30 km depth) magma chamber, are less than 300,000 years old and have resulted from seven periods of basaltic extrusion (Hoffer, 1971).

Black Mountain Area, Eastern La Mesa Surface

Black Mountain area is composed of eight volcanoes and at least six major flows (Hoffer, 1969; 1971; 1976). Four cinder cones are located in the center of the area, with the largest vent being the Black Mountain cone (diameter 610 m; height, more than 92 m). Small spatter cones are located to the north and south of the Black Mountain vent (Hoffer and others, 1991).

Little Black Mountain Area, Eastern La Mesa Surface

A single flow of olivine basalt is present at Little Black Mountain. It probably was extruded near the west end of the flow.

San Miguel Flow, Eastern La Mesa Surface

A single flow of olivine basalt is present at San Miguel. It probably was extruded near the west end of the flow. Lava of the San Miguel flow has been dated at 490,000$\pm$30,000 yrs B.P. (Seager and others, 1984), but stratigraphic evidence indicates an age of about 200,000 yrs B.P. (Gile, 1990).

Santo Tomas Flow, Eastern La Mesa Surface

Three flows and one major cinder cone make up the volcanic edifice of the Santo Tomas flow (Hoffer, 1971). Lava probably flowed to the northeast into the Rio Grande Valley from the La Mesa surface. The source of the lava was probably the Santo Tomas cone in the southwestern part of the flow.

Kilbourne Hole, Hunt's Hole, and Potrillo Maar are crater-like depressions termed maars—gaseous volcanoes that contain very little ejecta material. The features have rims with steep inner walls, gentle outer walls composed of talus blows and cinders, and a flat inner floor. These maars probably formed along the inferred, preexisting, down-to-the-west Fitzgerald fault. Gases probably escaped from an underlying near-surface magma.

Afton-Aden Craters area extends to the south and includes Kilbourne Hole, Hunt's Hole, and Potrillo Maar, three eruptive centers, which occur along the Robledo, Aden, and Fitzgerald faults. Afton Basalt and Aden Basalt, units within the Potrillo basalt field graben, are interpreted to be younger than middle Pleistocene and may be only a few thousand years old (Kottlowski, 1960;

Hoffer, 1976).

Afton Craters

Maar features of Afton Crater overlie a relatively undisturbed and flat-lying sedimentary section composed of La Mesa bolson-fill sediment, including gravel, sand, and caliche. Kilburn and others (1988) suggest that Permian and Cretaceous carbonate and clastic sedimentary rocks may also underlie the lava field.

Initial maar activity is marked by a single, basal layer of olivine basalt and a basal breccia formed when gaseous debris, country rock, and groundwater were mixed during ejection to the surface. Maar material overlying the basalt is composed of volcanic debris related to development of the maar, including tuff, scoriaceous bombs, olivine-cored bombs, pumice, and ash. Breccia present in the lowermost rim of the maar contains xenoliths of country rock brought up along the eruptive conduit, and olivine- and enstatite-cored bombs and layered tuffs. Rim deposits are typically well-bedded. Stratification records a later stage of deflation-induced crater filling by slumping during fault activity; late-stage lava may be extruded as a cap on the deposits. Major commodities derived from this area are scoria and pumice.

Aden Crater

Aden Crater (1,342 m), a small shield cone, is located in the northwestern part of Aden basalt field and northwest of Afton Craters. It is situated on the northern limb of the Pedrogosa basin (**figure 4-4.13**). Aden basalt was reportedly emplaced about 0.53 m.y. ago (Hawley, 1981; Seager and others, 1984) along fissures related to the Robledo fault (located by the presence of collapsed or subsided areas in the basalt) and the Aden rift (located by the presence of Aden crater, collapse structures, and Gardner cone).

Aden Crater is 5 km in diameter and about 50 m high (**figure 4-4.14**). Initially, basalt flows from a central vent built up a small shield cone. Gaseous ejecta later formed spatter cones around the edge of the crater and a wall. Basalt flows that are interpreted to represent a lava lake were ponded by the spatter on the outer rim. The lava lake breached the rim at several places, producing flows on the outer flanks of the volcano. Eventually the lake flowed back down the throat of the vent, and the lake solidified and collapsed over the vent. Minor fountaining occurred along fissures in the lake.

Spatter cones, a collapse depression, and a fumarole are located on the southeast rim of the crater (Hoffer, 1990; Hoffer and others, 1991). Other volcanic features in the basalt include lava tubes and channels, cracks, pressure ridges, and tumuli (small domes or mounds). Ground sloth remains within the fumarole deposits in the Aden lava cone date the maar activity as Recent (11,000 years; Simons and Alexander, 1964), and post-La Mesa-bolson in age. Dune sand covers

the crater basalt (Hoffer, 1976). Guano mining took place in the 1920s from the fumarole area (Kahn, 1987).

Kilbourne Hole

This maar volcano is the deepest of the Afton Craters. It is 2.9 km long and 2.3 km wide, with an elevation difference of 137 m from floor to crater rim (rising 52 m above the La Mesa bolson surface).

In the region of Kilbourne Hole, surficial sediments of the Santa Fe Group are about 702 m thick and are underlain by Tertiary volcanic rocks (Cordell, 1975). The basal deposit of the maar is a 4.5 m-thick basalt flow that sits atop caliche of the uppermost La Mesa bolson surface. Basalt is buried beneath rim volcanic rocks and talus, but is breached by a vent on the northern wall of the crater (Lee, 1907; Reiche, 1940). Overlying the basalt is an eruptive breccia as much as 15 m thick on the northern part of the crater, which thins southward to nil and contains olivine-cored and enstatite bombs. Overlying the breccia, stratified tuff deposits as thick as 38 m dip away from the center of the crater. Slump blocks up to 275 m in length occur along the walls. These deposits extend as far as 1.6 km from the crater rim and are folded on the northern edge. According to Seager (1987), the crater may have suffered caldera collapse at the end of the volcanic cycle, owing to the downfaulted material at the base of the inner crater wall and floor, and the relatively small amount of pyroclastic material deposited in relation to the overall crater size.

Geophysical data are equivocal concerning the subsurface lithology beneath the maar, but an anomalous zone of high-electrical conductivity occurs in a vertical pipe beneath the craters to a depth of 2 km, suggesting the presence of hot, saline, or clay-enriched water, possibly related to hydrothermal alteration. Cordell (1975) suggests that small amounts of hot, gaseous material erupted through shallow levels beneath Kilbourne Hole, but that the eruptive material may have been either solid or incandescent. Post-maar lavas have been dated at 180,000 yrs B.P. (Seager and others, 1984), and surficial weathering evidence atop the maar suggests an age of 24,000 yrs B.P. (Gile, 1987).

Hunt's Hole

Hunt's Hole is about 1.5 km in diameter, and has an elevation difference of 71 m from floor to rim crest (rising 31 m above the La Mesa surface). It sits atop deposits of the Santa Fe Group on the La Mesa surface. The basal deposit of the crater, exposed on the eastern wall, is a basalt flow that probably originates from Kilbourne Hole. The basalt extends to the south for 4.8 km. A 6 m-thick breccia deposit overlies the basalt and is exposed on the northeastern wall. Cored bombs are rare, although xenoliths and scoriaceous bombs are plentiful. Bedded tuff, which is as much as 14-15 m thick, makes up the rim overlying the breccia and is jointed radially

and tangentially to the crater. Rim deposits dip away from the center. Plant casts occur locally. Erosional evidence suggests that the maar formed less than 50,000 years ago (Stuart, 1981).

Potrillo Maar

Potrillo Maar occurs along the Mexico-U.S. border 16 km south of Hunt's Hole. The maar is 3 km x 5 km, with an elevation difference of about 61 m from floor to crater rim. Inner slopes of the crater are moderately steep. The central floor is composed of a basalt flow and clusters of cinder cones, some composed of scoria. Bedding is obscured by large amounts of blowsand. There is no apparent occurrence of eruptive breccia, although olivine-cored bombs are common, especially along the northeast rim. Tuff occurs locally as far away as 2.4 km northeast of the rim.

Phillip's Hole

Phillip's Hole occurs about 4.8 km east of Hunt's Hole. It does not fit the description of a maar. It is a depression about 3.2 km long, 2.3 km wide, and 21 m deep. There is no rim, and interior slopes are gentle. Origin of the depression is uncertain.

Mineral Resources

Scoria, pumice, and lava rock used in landscaping are commodities present in large quantities within the Afton and Aden Craters region. Peridot, the gemstone form of olivine, may be found in basaltic ejecta within xenolith bombs. Perlite deposits are present in volcanic sequences of the area. Guano has been mined from Aden Crater.

References

(* reference used in writing above summary)

Anthony, E.Y., Barnes, C.G., Chen, W., Hoffer, J.M., Keller, G.R., Marsaglia, K.M., McLemore, V.T., Seeley, J.M., Seward, M.A., Shannon, W.M., and Thomann, W.F., 1991, Examples of modern rift volcanism and Proterozoic anorogenic magmatism--The Potrillo volcanic field of southern New Mexico and the Franklin Mountains of west Texas, *in* Julian, Betsy, and Zidek, Jiri, Field guide to geologic excursions in New Mexico and adjacent areas of Texas and Colorado: New Mexico Bureau of Mines and Mineral Resources Bulletin 137, p. 1-19.

Aubele, J.C., Crumpler, L. S., Loeber, K.N., and Kudo, A.M., 1976, Maare and tuff rings of New Mexico, *in* Woodward, L.A., and Northrop, S.A., eds., Tectonics and mineral resources of southwestern North America: New Mexico Geological Society Special Publication No. 6, p. 109-114.

Bahar, D., 1991, Stratigraphy of the base-surge deposits at the southern end of Kilbourne Hole maar, southern New Mexico: Proceedings of the 1990 New Mexico Geological Society

meeting, New Mexico Geology, v. 13, no. 2, p. 39.

Berman, R.G., and Reid, J.B., Jr., 1976, The deep-seated evolution of highly undersaturated basaltic magmas; evidence from kaersutite-gabbro inclusions, West Potrillo Mountains, New Mexico: Eos, American Geophysical Union, Transactions, v. 57, no. 4, p. 354-355.

*Bersch, M.G., 1977, Petrography and geology of the southern West Potrillo Basalt Field, Doña Ana County, New Mexico: El Paso, University of Texas, unpublished Master's thesis, 60 p.

Bowers, W.E., 1960, Geology of the East Potrillo Hills, Doña Ana County, New Mexico: University of New Mexico, unpublished Master's thesis, 67 p.

Bussod-Giles, Y.A., and Irving, A.J., 1981, Thermal and rheologic history of the upper mantle beneath the southern Rio Grande Rift --Evidence from Kilbourne Hole xenoliths: Papers presented to the Conference on the processes of planetary rifting; LPI Contribution 457, p. 145-148.

Bussod-Giles, Y.A., and Williams, D.R., 1991, Thermal and kinematic model of the southern Rio Grande Rift; inferences from crustal and mantle xenoliths from Kilbourne Hole, New Mexico, *in* Gangi, A.F., ed., World Rift Systems: Tectonophysics, v. 197, nos. 2-4, p. 373-389.

*Clemons, R.E., 1993, Petrographic analysis of Cenozoic-Mesozoic-Permian well cuttings from two exploration wells in south-central New Mexico: Socorro : New Mexico Bureau of Mines and Mineral Resources Circular 203, 28 p.

*Cordell, Lindrith, 1975, Combined geophysical studies at Kilbourne Hole maar, New Mexico, *in* Seager, W.R., Clemons, R.E., and Callender, J.F., ed., Guidebook of the Las Cruces Country: New Mexico Geological Society, 26th Annual Field Conference Guidebook, p. 269-271.

DeHon, R., 1965a, The Aden Crater lava cone: Compass, v. 43, p. 34-40.

*DeHon, R.A., 1965, Maare of La Mesa, *in* Fitzsimmons, J.P., and Lochman-Balk, Christina, eds., Guidebook of southwestern New Mexico II: New Mexico Geological Society, 16th Field Conference, p. 204-209.

Dromgoole, E.L., and Pasteris, J.D., 1987, Interpretation of the sulfide assemblages in a suite of xenoliths from Kilbourne Hole, New Mexico, *in* Morris, E.M., and Pasteris, J.D., eds., Mantle metasomatism and alkaline magmatism: Sul Ross State University, Alpine, Texas, Geological Society of America Special Paper 215, p. 25-46.

Feingenson, M.D., 1986, Continental alkali basalts as mixtures of kimberlite and depleted mantle; evidence from Kilbourne Hole maar, New Mexico: Geophysical Research Letters, v. 13,

no. 9, p. 965-968.

Frantes, T.J., and Hoffer, J.M., 1982, Palomas volcanic field, southern New Mexico and northern Chihuahua, Mexico: New Mexico Geology, v. 4, no. 1, p. 6-8, 16.

Fuhrbach, J.R., 1990, Kilbourne Hole maar peridot, Doña Ana County, New Mexico: 11th Annual New Mexico Mineral Symposium Proceedings, p. 9.

*Gese, D.D., 1985, Mineral resources of the West Potrillo Mountains/Mt. Riley Study Area and the Aden Lava Flow Wilderness Study Area, Doña Ana and Luna Counties, New Mexico: U.S. Bureau of Mines Open-file Report MLA 74-85, 19 p.

Gile, L.H., 1987, A pedogenic chronology for Kilbourne Hole, southern New Mexico; II-- Time of the explosions and soil events before the explosions: Soil Science Society of America Journal, v. 51, no. 3, p. 752-760.

Gile, L.H., 1990, Chronology of lava and associated soils near San Miguel, New Mexico: Quaternary Research, v. 33, no. 1, p. 37-50.

*Gillerman, Elliot, 1952, Fluorspar deposits of the Burro Mountains and vicinity: U.S. Geological Survey Bulletin 973-F, p. 261-289.

Grew, E.S., 1979, Al-Si disorder of K-feldspar in crustal xenoliths at Kilbourne Hole, New Mexico: American Mineralogist, v. 64, no. 7-8, p. 912-916.

Hart, S.R., Padovani, E., and Richardson, S., 1980, Geochemistry of lower crustal granulite xenoliths, Kilbourne Hole, New Mexico: International Geological Congress Abstracts, no. 26, v. 2, p. 775.

Hart, S.R., Padovani, E.R., and Roden, M.K., 1979, Sr-isotopic relationships in lower crustal nodules from Kilbourne Hole, New Mexico [abs.]: Geological Society of America Abstracts with Programs, v. 11, no. 7, p. 439.

Heylmun, E.B., 1986, East Potrillo Mountains, New Mexico: California Mining Journal, v. 55, no. 5, p. 10-12.

*Hoffer, J.M., 1969, Volcanic history of the Black Mountain-Santo Tomas basalts, Potrillo volcanics, Doña Ana County, New Mexico, *in* Cordoba, D.A., Wengerd, S.A., and Shomaker, J., eds., Guidebook of the Border Region; Chihuahua and the United States: New Mexico Geological Society, 20th Annual Field Conference, p. 108-114.

*Hoffer, J.M., 1971, Herradura: A new lava flow feature: Geological Society of America Bulletin, v. 82, p. 2949-2954.

*Hoffer, J.M., 1971, Mineralogy and petrology of the Santo Tomas-Black Mountain basalt field, Potrillo volcanics, south-central New Mexico: Geological Society of America Bulletin, v. 82, p. 603-612.

Hoffer, J.M., 1973, Summary of the Cenozoic geology of southern Doña Ana County, New Mexico, *in* El Paso Geological Society, 7th Annual Fieldguide: p. 12-15.

*Hoffer, J.M., 1975, A note on the volcanic features of the Aden Crater area, southcentral New Mexico, *in* Seager, W.R., Clemons, R.E., and Callender, J.F., eds., Guidebook of the Las Cruces Country: New Mexico Geological Society, 26th Annual Field Conference, p. 131-134.

*Hoffer, J.M., 1976, Geology of Potrillo Basalt field, south-central New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 149, 30 p.

*Hoffer, J.M., 1976, The Potrillo Basalt field, south-central New Mexico *in* Elston, W.E., and Northrop, S.A., eds., Cenozoic volcanism in southwestern New Mexico: New Mexico Bureau of Mines and Mineral Resources Special Publication 5, p. 89-92.

Hoffer, J.M., 1986, Subsurface volcanic stratigraphy, southern New Mexico, *in* Hoffer, J.M., ed., Geology of southcentral New Mexico: El Paso Geological Society Field Trip Guidebook, April 11, 1986, p. 119-122.

Hoffer, J.M., 1990, Geologic tour of Aden Crater: El Paso Geological Society, Guidebook to the Fall 1990 Field Trip, 42 p.

*Hoffer, J.M., Chen, W., McLemore, V.T., and Anthony, E.Y., 1991, Day 2--The Potrillo volcanic field, *in* Julian, Betsy, and Zidek, Jiri, Field guide to geologic excursions in New Mexico and adjacent areas of Texas and Colorado: New Mexico Bureau of Mines and Mineral Resources Bulletin 137, p. 12-19.

Hoffer, J.M., and Hoffer, R.L., 1973, Composition and structural state of feldspar inclusions from alkali olivine basalt, Potrillo basalt, southern New Mexico: Geological Society of America Bulletin 84, p. 2139-2142.

Hoffer, J.M., and Hoffer, R.L., 1981, A note on Lower Cretaceous outcrops, southeastern Luna County, New Mexico, *in* Hoffer, J.M., and Hoffer, R.L., eds., Geology of the border; southern New Mexico-northern Chihuahua: El Paso Geological Society Guidebook, p. 54-56.

Hoffer, J.M., and Hoffer, R.L., 1981, Geology of the East Potrillo Mountains, southern Doña Ana County, New Mexico, *in* Hoffer, J.M., and Hoffer, R.L., eds., Geology of the border; southern New Mexico-northern Chihuahua: El Paso Geological Society Guidebook, p. 57-61.

Hoffer, J.M., and Ortiz, T.S., 1981, The composition of feldspar megacrysts, Potrillo basalt, West Potrillo Mountains, southern New Mexico, *in* Hoffer, J.M., and Hoffer, R.L., eds., Geology of the border--Southern New Mexico-Northern Chihuahua: El Paso Geological

Society, p. 73-78.

Hoffer, J.M., and Sheffield, T.M., 1981, Geology of the West Potrillo Mountains, south-central New Mexico: El Paso Geological Society, Guidebook, p. 79-82.

Hoover, D.B., and Tippens, C.L., 1975, A reconnaissance audio-magnetotelluric survey at Kilbourne Hole, New Mexico, *in* Seager, W.R., Clemons, R.E., and Callender, J.F., eds., Guidebook of the Las Cruces Country: New Mexico Geological Society, 26th Annual Field Conference, p. 277-278.

Irving, A.J., 1979, Kilbourne Hole spinel lherzolites--Samples of multiply depleted, enriched and deformed mantle: Eos, American Geophysical Union, Transactions, v. 60, no. 18, p. 418.

Jackson, D.B., and Bisdorf, R.J., 1975, Direct-current soundings on the La Mesa surface near Kilbourne and Hunts holes, New Mexico, *in* Seager, W.R., Clemons, R.E., and Callender, J.F., eds., Guidebook of the Las Cruces Country; New Mexico Geological Society, 26th Annual Field Conference, p. 273-275.

James, D.E., Padovani, E.R., and Hart, S.R., 1980, Preliminary results on the oxygen isotopic composition of the lower crust, Kilbourne Hole maar, New Mexico: Geophysical Research Letters, v. 7, no. 5, p. 321-324.

Jones, J.L., Kilburn, J.E., Zimbelman, D.R., and Siems, D.F., 1987, Analytical results and sample locality maps of heavy-mineral-concentrate and rock samples from the West Potrillo Mountains/Mt. Riley Wilderness Study Area (030-052), Luna and Doña Ana Counties, New Mexico: U.S. Geological Survey Open-File Report 87-265.

*Kahn, P.A. 1987, Geology of Aden Crater, Doña Ana County, New Mexico: El Paso, University of Texas, unpublished Master's thesis, 90 p.

*Kilburn, J.E., Stoeser, D.B., Zimbelman, D.R., Hanna, W.F, and Gese, D.D., 1988, Mineral Resources of the West Potrillo Mountains-Mount Riley and the Aden Lava Flow Wilderness Study Areas, Doña Ana and Luna Counties, New Mexico: U.S. Geological Survey Bulletin 1735, Chapter B, p. B1-B14.

Lee, W.T., 1907, Afton Craters of southern New Mexico: Geological Society of America Bulletin, v. 18, no. 5, p. 211-220.

Lindberg, J.D., 1964, The peridot deposits of Kilbourne Hole, New Mexico: Lapidary Journal, v. 18, no. 7, p. 768-771.

Lindberg, J.D., 1984, Olivine, spinel, feldspar, and other curiosities from Riley Maar, New Mexico: Lapidary Journal, v. 38, no. 9, p. 1192-1196.

*Luedke, R.G., and Smith, R.L., 1978, Map showing distribution, composition, and age of Late Cenozoic volcanic centers in Arizona and New Mexico: U.S. Geological Survey

Miscellaneous Investigations Series Map I-1091-A, scale 1:1,000,000.

Mack, G.H., 1986, Lower Cretaceous stratigraphy and depositional environments in the East Potrillo Mountains and adjacent areas of southwestern New Mexico, *in* Hoffer, J.M., ed., Geology of southcentral New Mexico: El Paso Geological Society Guidebook, p. 85-94.

O'Donnell, J.E., Martinez, R., and Williams, J., 1975, Telluric current sounding near Kilbourne and Hunts Holes, New Mexico, *in* Seager, W.R., Clemons, R.E., and Callender, J.F., eds., Guidebook of the Las Cruces Country: New Mexico Geological Society, 26th Annual Field Conference, p. 279-280.

Ortiz, T.S., 1979, Megacrysts and mafic and ultramafic inclusions of the southern West Potrillo Basalt Field, Doña Ana County, New Mexico: El Paso, University of Texas, unpublished Master's thesis, 95 p.

Padovani, E.R., 1977, Granulite facies xenoliths from Kilbourne Hole maar, New Mexico, and their bearing on deep crustal evolution: Dallas, University of Texas, unpublished Ph. D. dissertation, 172 p.

Padovani, E.R., 1986, The ground truth from crustal xenoliths; a multifaceted approach, *in* Noller, J.S., Kirby, S.H., and Neilson-Pike, J.E., eds., Geophysics and petrology of the deep crust and upper mantle; a workshop sponsored by the U.S. Geological Survey and Stanford University: U.S. Geological Survey Circular 0956, p. 40-43.

Padovani, E.R., and Carter, J.L., 1973, Mineralogy and mineral chemistry of a suite of anhydrous, quartzo-feldspathic, garnet-bearing granulites from Kilbourne Hole maar, New Mexico [abs.]: Geological Society of America Abstracts, v. 5, no. 7, p. 761-762.

Padovani, E.R., and Carter, J.L., 1974, Blue sillimanite in garnet granulite xenoliths from Kilbourne Hole, New Mexico: Eos, American Geophysical Union Transactions, v. 55, no. 4, p. 482.

Padovani, E.R., and Carter, J.L., 1977, Non-equilibrium partial fusion due to decompression and thermal effects in crustal xenoliths, *in* Dick, H.J.B., ed., Magma genesis 1977--Proceedings of the American Geophysical Union Chapman conference on partial melting in the Earth's upper mantle: Oregon Department of Geology and Mineral Industries Bulletin 96, p. 43-57.

Padovani, E.R., and Carter, J.L., 1978, Aspects of the deep crustal evolution beneath south-central New Mexico, *in* Heacock, J.G., Keller, G.V., Oliver, J.E., and Simmons, G., eds., The Earth's crust; its nature and physical properties: American Geophysical Union, Geophysics Monographs, v. 20, p. 19-55.

Padovani, E.R., and Carter, J.L., 1978, Deep crustal evolution beneath south-central New

Mexico--Constraints on the geothermal gradient from xenolithic assemblages, *in* Olden, K.H., and Chapin, C.E., eds., International symposium on the Rio Grande Rift; Program and abstracts: Los Alamos Scientific Laboratory report LA-C 7487, p. 66-67.

*Page, R.O., 1975, Malpais maar volcano, *in* Seager, W.R., Clemons, R.E., and Callender, J.F., eds., Guidebook of the Las Cruces Country: New Mexico Geological Society, 26th Annual Field Conference Guidebook, p. 135-137.

Perry, F.V., Baldridge, W.S., and DePaolo, D.J., 1987, Role of asthenosphere and lithosphere in the genesis of Late Cenozoic basaltic rocks from the Rio Grande Rift and adjacent regions of the southwestern United States: Journal of Geophysical Research, v. 92, no. B9, p. 9193-9213.

Pike, J.E.N., 1980, Composite spinel lherzolite/spinel-olivine pyroxenite/metagabbroid xenolith from Kilbourne Hole, New Mexico, *in* Irving, A.J., and Dungan, M.A., eds., The Jackson Volume: American Journal of Science, v. 280-A, part: p. v-vi.

Reeves, C.C., Jr., and De Hon, R.A, 1965, Geology of Potrillo Maar, New Mexico and northern Chihuahua, Mexico: American Journal of Science, v. 263, p. 401-409.

Reiche, Parry, 1940, The origin of Kilbourne Hole, New Mexico: American Journal of Science, v. 238, no. 3, p. 212-225.

Reid, J.B., Jr., 1977, A comparison of partial melting processes beneath Hawaii and the southern Rio Grande Rift, *in* Dick, H.J.B., ed., Magma genesis 1977--Proceedings of the American Geophysical Union Chapman conference on partial melting in the Earth's upper mantle: Oregon Department of Geology and Mineral Industries Bulletin 96, p. 307.

Reid, M.R., 1989, Compositional dependence of Pb isotopic signatures in the lower crust exhibited by xenoliths from Kilbourne Hole, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 131, p. 222.

Reid, M.R., Hart, S.R., Padovani, E.R., and Wandless, G.A., 1989, Contribution of metapelitic sediments to the composition, heat production, and seismic velocity of the lower crust of southern New Mexico, USA: Earth and Planetary Science Letters, v. 95, nos. 3-4, p. 367-381.

Renault, J., 1970, Major-element variations in the Potrillo, Carrizozo, and McCartys basalt fields, New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 113, 22 p.

Roden, M.F., Irving, A.J., and Murthy, V.R., 1988, Isotopic and trace element composition of the upper mantle beneath a young continental rift; results from Kilbourne Hole, New Mexico: Geochimica et Cosmochimica Acta, v. 52, no. 2, p. 461-473.

Seager, W.R., 1987, Caldera-like collapse at Kilbourne Hole maar, New Mexico: New Mexico

Geology, v. 9, p. 69-73.

Seager, W. R., and Mack, G. H., in press, Geology of East Potrillo Mountains and vicinity, Doña Ana County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 113.

Seager, W.R., and Mack, G.H., 1986, Summary of geology of East Potrillo Mountains area: El Paso Geological Society, Guidebook, p. 158-159.

Seager, W.R., Shafiqullah, M., and Clemons, R.E., 1981, Active fault analysis and radiometric dating of young basalts in southern New Mexico, *in* Icerman, L. Starkey, A., and Trentman, N., eds., State-coupled low temperature geothermal resource assessment program, fiscal year 1981, Final technical report: New Mexico Energy Institute at New Mexico State University, p. 6-1 - 6-7.

Seager, W.R., Shafiqullah, M., Hawley, J.W., and Marvin, R., 1984, New K-Ar dates from basalt and the evolution of the southern Rio Grande Rift: Geological Society of America Bulletin, v. 95, no. 1, p. 87-99.

Seager, W.R., Hawley, J.W., Kottlowski, F.E., and Kelley, S.A., 1987, Geology of east half of Las Cruces and northeast El Paso 1° x 2° sheets, New Mexico: New Mexico Bureau of Mines and Mineral Resources Geologic Map 57, scale 1:125,000.

Shoemaker, E.M., 1957, Primary structures of maar rims and their bearing on the origin of Kilbourne Hole and Zuni Salt Lake, New Mexico [abs.]: Geological Society of America Bulletin, v. 68, no. 12, p. 1864.

Simons, E.L., and Alexander, N.L., 1964, Age of the Shasta ground sloth from Aden Crater, New Mexico: American Antiquity, v. 29, no. 3, p. 390-391.

Stuart, C.J., 1981, Hunt's Hole maar volcano, Doña Ana County, south-central New Mexico: El Paso Geological Society, Guidebook, p. 64-72.

Stuart, C.J., and Brenner, M.G., 1979, "Low-regime" base surge dunes--An example from Kilbourne and Hunt's holes, south-central New Mexico [abs.]: Geological Society of America Abstracts with Programs, v. 11, no. 7, p. 525.

Towle, J.N., and Fitterman, D.V., 1975a, Geomagnetic variations at Kilbourne Hole, New Mexico, *in* Seager, W.R., Clemons, R.E., and Callender, J.F., eds., Guidebook of the Las Cruces Country: New Mexico Geological Society, 26th Annual Field Conference, p. 281.

Towle, J.N., and Fitterman, D.V., 1975b, Geomagnetic variations at Kilbourne Hole, New Mexico, *in* Seager, W.R., Clemons, R.E., and Callender, J.F., eds., Guidebook of the Las Cruces Country: New Mexico Geological Society, 26th Annual Field Conference, p.

RINCON HILLS

General Geology

In the low mountains, hogbacks, cuestas, and badlands that make up the Rincon Hills in northwestern Doña Ana County, Paleozoic rocks are overlain unconformably by Cenozoic volcanic and sedimentary rocks, including the Love Ranch Formation, Palm Park Formation, Thurman Formation and Uvas Andesite, Santa Fe Group (including the Hayner Ranch Formation and Rincon Valley Formation), and Quaternary fluvial and terrace deposits (including the Camp Rice Formation) of the ancestral and present-day Rio Grande. Rincon Hills represent an early rift basin (Chapin and Seager, 1975). As at other locations along the Rio Grande Rift, Miocene Santa Fe Group deposits interfinger with tuff-bearing sediments that, in turn, interfinger with the Uvas Andesite. These deposits correlate with deposits in the Cedar Hills depression (see "Sierra de las Uvas"), where initial movement on the Rio Grande Rift occurred at 26 m.y.

Structurally, the Rincon Hills are tilted and uplifted by north- to northwest-trending high-angle, normal faults; strata are gently dipping to the south, southwest, and southeast, and gently folded. Rincon Hills were uplifted into a series of stepped half grabens (stair-stepped horsts) that culminate in the uplifted fault block of the adjacent Caballo Mountains (outside of the study area northeast of the Rincon Hills).

East and West Rincon Hills faults and the Central fault are the major faults within the Rincon Hills, separating the Rincon Hills from adjacent grabens. Faulting took place from Miocene to Recent time. Evidence for Laramide folding and thrust faulting is only subtly present in the structural relations of the Love Ranch Formation and underlying Paleozoic sequences in the Caballo Mountains.

References

(* reference used in writing above summary)

Basler, J.A., and Alary, L.J., 1968, Quality of the shallow ground water in the Rincon and Mesilla Valleys, New Mexico and Texas: U.S. Geological Survey Open-File Report, 30 p.

Hawley, J.W., Seager, W.R., and Clemons, R.E., 1975, Third Day road log from Las Cruces to north Mesilla Valley, Cedar Hills, San Diego Mountain, and Rincon area, *in* Seager, W.R., Clemons, R.E., and Callender, J.F., eds., Las Cruces Country: New Mexico Geological Society 26th field conference guidebook, p. 35-53.

*Seager, W.R., and Hawley, J.W., 1973, Geology of Rincon quadrangle, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 101, 42 p., scale 1:24,000.

Wilson, C.A., White, R.R., Orr, B.R., and Roybal, R.G., 1981a, Water resources of the Rincon

and Mesilla valleys and adjacent areas, New Mexico: U.S. Geological Survey Open-File Report 81-0487, 447 p.

RIO GRANDE VALLEY

General Geology

In the Mimbres Resource Area adjacent to the Rio Grande river, sequences of terraces that represent varying levels of the ancestral Rio Grande during late Cenozoic time are present (**figure 4-4.15**). Various levels are correlatable along the flanks of the river throughout much of New Mexico. Basalt flows and volcanic ash beds are dispersed throughout the depositional sequence. All of the deposits comprise the late Cenozoic Santa Fe Group (**appendix B**).

Prior to entrenchment of the ancestral Rio Grande, the region was characterized by internally drained basins (bolsons) flanked by north-trending mountain ranges. Remnants of these basin-plain surfaces include the Palomas basin, Jornada del Muerto, and the Mesilla bolson. An older surface (of middle Pleistocene age as determined from vertebrates found on it) is termed the La Mesa surface (Ruhe, 1964), and it occurs at the highest level in the vicinity of Las Cruces. It represents the ancient basin surface prior to major entrenchment. This surface is capped by extensive layers (up to 18 m thick) of caliche, sand, and gravel. These Quaternary sediments probably were over 153 m thick, and probably consisted of piedmont slope, basinal, and playa deposits (Hawley and Kottlowski, 1969).

Through-going drainage along the Rio Grande was probably established in latest Miocene and (or) Pliocene time during culmination of rifting. The oldest known river deposits of the through-going ancestral Rio Grande are 2-3 m.y. old. They rest on early basin fill in the Las Cruces area, and were apparently deposited by a river with a similar alignment to the present-day Rio Grande.

The Jornada piedmont-slope surface (Ruhe, 1964) was formed subsequent to the development of the La Mesa surface and during a period of pedimentation and alluvial-fan deposition from the nearby mountains. Doña Ana piedmont-slope surface, similar in genesis, is older than the Jornada surface and may be correlative to the La Mesa basin-plain surface.

After formation of the basin-plain and pediment-slope surfaces in Early to Middle Pleistocene and Pliocene time, four cycles of river and arroyo entrenchment occurred in Late Pleistocene to Recent time that were accompanied by aggradation. These cycles are represented by successive terrace levels above the present-day Rio Grande valley floor and represent hiatuses in entrenchment of the Rio Grande; they can be correlated to the south from Albuquerque to El Paso (Hawley and Kottlowski, 1969). These levels are, from oldest to youngest, the Tortugas, Picacho, and Fort Selden surfaces.

Faulting has resulted in changes in the course of the Rio Grande in late Pleistocene time, with offsets of as much as 61 m locally (along the Robledo Fault, for example). Effects of tectonism result in warped and faulted geomorphic surfaces. Fault deformation has continued into Recent time (over the past 10,000 yrs). Volcanic flows (the West Potrillo Mountains volcanic field) are present atop the La Mesa surface between the Potrillo Mountains and the Mesilla Valley. Some of the basalt flows interfinger with the upper Santa Fe Group sediments, and most post-date the La Mesa surface.

Mineral Resources

Large aggregate and pumice deposits are found along and adjacent to the Rio Grande.

References

(* reference used in writing above summary)

Bachman, G.O., and Mehnert, H.H., 1978, New K-Ar dates and the late Pliocene to Holocene geomorphic history of the central Rio Grande region, New Mexico: Geological Society of America Bulletin, v. 89, no. 2, p. 283-292.

Chapin, C.E., and Seager, W.R., 1975, Evolution of the Rio Grande Rift in the Socorro and Las Cruces areas, *in* Seager, W.R., Clemons, R.E., and Callender, J.F., eds., Guidebook of the Las Cruces Country: New Mexico Geological Society, 26th Annual Field Conference, p. 297.

Gile, L.H., 1970, Soils of the Rio Grande valley border in southern New Mexico: Soil Science Society of America, Proceedings, v. 34, no. 3, p. 465-472.

*Hawley, J.W., 1965, Geomorphic surfaces along the Rio Grande valley from El Paso, Texas, to Caballo Reservoir, New Mexico, *in* Fitzsimmons, J.P., and Lochman-Balk, Christina, eds., Guidebook of southwestern New Mexico II: New Mexico Geological Society, 16th Field Conference, p. 188-198.

Hawley, J.W., Kottlowski, F.E., Seager, E.R., King, W.E., Strain, W.S., and LeMone, D.V., 1969, The Santa Fe Group in the southcentral New Mexico border region, *in* Border stratigraphy symposium: New Mexico Bureau of Mines and Mineral Resources Circular 104, p. 52-76.

*Hawley, J.W., and Kottlowski, F.E., 1969, Quaternary geology of the south-central New Mexico border region, *in* Border stratigraphy symposium: New Mexico Bureau of Mines and Mineral Resources Circular 104, p. 89-104.

Kottlowski, F.E., 1953, Tertiary-Quaternary sediments of the Rio Grande valley in southern New Mexico, *in* Kottlowski, F.E., ed., Southwestern New Mexico: New Mexico Geological Society Guidebook, 4th Annual Field Conference, p. 144-147.

Kottlowski, F.E., 1958, Geologic history of the Rio Grande near El Paso, *in* Nelson, L.A. and Haigh, B.R., leaders, Franklin and Hueco Mountains, Texas: West Texas Geological Society Fieldtrip Guidebook, p. 46-54.

Kottlowski, F.E., 1965, Sedimentary basins of south-central and southwestern New Mexico: American Association of Petroleum Geologists Bulletin, v. 49, no. 11, p. 2120-2139.

Metcalf, A.L., 1967, Late Quaternary mollusks of the Rio Grande valley, Caballo Dam, New Mexico, to El Paso, Texas: El Paso, University of Texas, Texas Western Press, Science Series I, 62 p.

Ruhe, R.V., 1962, Age of the Rio Grande Valley in southern New Mexico: Journal of Geology, v. 70, p. 151-167.

Ruhe, R.V., 1964, Landscape morphology and alluvial deposits in southern New Mexico: Annals Association of American Geographers, v. 54, p. 147-159.

Ruhe, R.V., 1967, Geomorphic surfaces and surficial deposits in southern New Mexico: New Mexico Bureau of Mines and Mineral Resources Memoir 18, 66 p.

Seager, W.R., 1977, Rio Grande Rift in southern New Mexico [abs.]: Geological Society of America Abstracts with Programs, v. 9, no. 1, p. 72.

U.S. Reclamation Service, 1914, Map of Mesilla Valley showing various known river channels: Rio Grande project, New Mexico-Texas, U.S. Department of Interior, Bureau of Reclamation.

ROBLEDO MOUNTAINS

General Geology

Robledo Mountains are a south-tilted, wedge-shaped horst of Paleozoic sedimentary and Tertiary volcanic rocks located northwest of Las Cruces and west of the Rio Grande (**figure 4-4.16**). Rock units in the Robledo Mountains are subsurface Precambrian rocks, Bliss Formation, El Paso Limestone, and exposed units that include the upper beds of the El Paso Limestone, and the Montoya Group (Cable Canyon Sandstone, Upham Dolomite, Aleman Dolomite, and Cutter Dolomite, Fusselman Dolomite (erosionally thinned northward), Percha Shale, Caballero Formation, Pennsylvanian strata (203 m thick), Bursum Formation, intertonguing Hueco Group-Abo Formation, and Tertiary clastic and volcanic rocks (about 101 m thick). Santa Fe Group deposits are as much as 171 m thick. Partly eroded Quaternary basalt flows, cones, and necks that resulted from separate eruptions are exposed in the Robledo Mountains.

A Permian dinosaur tracksite is located in the Robledo Mountains, which includes thousands of trails and tracks of invertebrate and vertebrate animals. The trackway is in exposures of the Abo-Hueco Formations containing of ripple-laminated silty sandstone. The rocks contain

raindrop imprints and mudcracks in addition to the foot imprints. The original environment is interpreted to be an intertidal zone subjected to frequent exposure.

References

(* reference used in writing above summary)

Hawley, J.W., and Kottlowski, F.E., 1965, Road log from Las Cruces to Nutt, *in* Fitzsimmons, J.P., and Lochman-Balk, Christina, eds., Guidebook of southwestern New Mexico II: New Mexico Geological Society, Sixteenth Field Conference, 244 p.

James, W.C., and Mack, G.H., 1986, Abo-Hueco transition zone (Lower Permian) of the Robledo Mountains and adjacent areas of southwestern New Mexico, *in* Hoffer, J.M., ed., Geology of southcentral New Mexico: El Paso Geological Society Field Trip Guidebook, p. 67-72.

Kohn, P.A., and Dewey, C.P., 1990, Permian ostracodes from the upper Hueco Formation, Robledo Mountains, New Mexico: The Compass, v. 67, no. 4, p. 217-224.

*Kottlowski, F.E., 1960, Reconnaissance geologic map of Las Cruces 30' quadrangle: New Mexico Bureau of Mines and Mineral Resources Geologic Map 14, scale 1:126,720.

*Kottlowski, F.E., Foster, R.W., and Wengerd, S.A., 1969, Key oil tests and stratigraphic sections in southwest New Mexico, *in* Cordoba, D.A., Wengerd, S.A., and Shomaker, J., eds., Guidebook of the Border Region; Chihuahua and the United States: New Mexico Geological Society, 20th Annual Field Conference, p. 186-196.

*Lucas, S.G., 1993, Geological context of Permian tracksite, Robledo Mountains, Doña Ana County, New Mexico: Proceedings volume, 1993 Annual Spring Meeting, New Mexico Geological Society, Socorro, p. 40.

Roepke, T.J., 1983, Preliminary analysis--Pennsylvanian stratigraphy of Robledo Mountains, Doña Ana County, New Mexico [abs.]: New Mexico Geology, v. 5, no. 3, p. 65.

ROUGH AND READY HILLS

General Geology

Rough and Ready Hills, which extend southward from the Cedar Hills and northward from the Sleeping Lady Hills, are a north-trending, west-tilted block uplift along the Cedar Hills Fault zone. Rough and Ready Hills formed during Basin-and-Range extensional activity along the Rio Grande Rift. Exposed rocks are composed mainly of the Cedar Hills flow-banded rhyolite and the upper tuffaceous sedimentary member and basaltic andesite member of the Bell Top Formation (**figure 4-4.17**). These units are overlain by the Uvas Andesite, the Rincon Valley Formation, and deposits of the Camp Rice Formation. Late Pleistocene and Holocene deposits include valley and piedmont-slope alluvium and windblown sand.

Mineral Resources

Aggregate deposits exist in the Rough-and-Ready Hills.

References

(* reference used in writing above summary)

*Clemons, R.E., 1976, Geology of east half Corralitos Ranch quadrangle, New Mexico: New Mexico Bureau of Mines and Mineral Resources Geologic Map 36, scale 1:24,000.

Clemons, R.E., 1977, Geology of west half Corralitos Ranch quadrangle, New Mexico: New Mexico Bureau of Mines and Mineral Resources Geologic Map 44, scale 1:24,000.

SAN ANDRES MOUNTAINS

(See Organ-San Andres Mountains)

SAN DIEGO MOUNTAIN-TONUCO UPLIFT

San Diego Mountain is southeast of the Rincon Hills and north of the Doña Ana Mountains east of the Rio Grande in northern Doña Ana County. Tonuco Uplift is west of the Rio Grande.

General Geology

North-trending Tonuco uplift and the West Selden Hills uplift, structural features of which San Diego Mountain is a part, are en-echelon fault-bounded horsts containing Precambrian through Tertiary age rock units. Units present in the uplift are Precambrian rocks, Bliss Formation, Sierrite Member of the El Paso Limestone, Fusselman Dolomite, Oñate Formation, Hueco Group, Abo Formation, Love Ranch Formation, Palm Park Formation, Bell Top Formation, Doña Ana monzonite porphyry, Uvas Andesite, and lower Santa Fe Group rocks (Hayner Ranch Formation and Rincon Valley Formation, including the Selden Basalt Member of Rincon Valley Formation). The major part of the block uplift occurred during extensional Basin-and-Range events associated with the Rio Grande Rift, but the rocks exhibit evidence of previous basement-cored folding and thrust faulting that took place during compressional Laramide events, forming the west-northwest-trending Rio Grande uplift (Seager and Mack, 1986) (**figure 1-5**). San Diego Mountain is on the northern boundary of the uplift.

Overlapping Tertiary tectonic events have shaped the patterns of deposition and erosion in the region. The earliest tectonic event was Laramide uplift, and resulting thicknesses of sedimentary rocks are deposited along the flanks of the north-trending Tonuco uplift. Unconformities are present at the base of the Tertiary section. The Laramide uplift is inferred to be anticlinal, with both folding and thrust faulting on the eastern limb indicating eastward transport. The majority of rock units now exposed result from Cenozoic volcanism and block faulting. In Oligocene time, tectonic events associated with the Good Sight-Cedar Hills volcano-tectonic

depression resulted in deposition of thick sections of ash-flow tuffs, rhyolite intrusions, epiclastic sediments, and basaltic andesite flows. West Selden Hills fault marks the north-trending zone of block faulting and intrusive activity. The fault scarp was a barrier to deposition of the Uvas Basaltic Andesite lavas and Bell Top Formation ash flows. The final tectonic event in the region (ongoing) is block faulting associated with the Rio Grande Rift. Erosion and deposition of thick accumulations of fanglomerate and fluvial deposits from the uplifts have filled Tertiary grabens (Santa Fe Group and younger deposits).

Three episodes of volcanism are apparent in the San Diego Mountain/Tonuco Uplift area. Palm Park Formation and andesite-latite deposits are faulted against Precambrian granite and metamorphic rocks in isolated exposures, lower Paleozoic units including Bliss Formation and El Paso Limestone, and the Love Ranch Formation (Kottlowski, 1953; Condie and Budding, 1979; Seager and others, 1971). Palm Park Formation is overlain by the volcaniclastic and volcanic rocks of the Bell Top Formation. Finally, dikes of basaltic andesite, probably associated with the Uvas Andesite, intrude earlier rocks.

Depositional sequences of the Santa Fe Group are unconformable on underlying deposits, and were formed during development of the ancestral Rio Grande Valley. Today the Rio Grande is entrenched about 107 m below the La Mesa and terrace surfaces.

References

(* reference used in writing above summary)

Clemons, R.E., 1973, Geology of the Souse Springs quadrangle, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 100, 31 p.

*Condie, K.C., and Budding, A.J., 1979, Geology and geochemistry of Precambrian rocks, central and south-central New Mexico: New Mexico Bureau of Mines and Mineral Resources Memoir 35, 58 p.

Hawley, J.W., and Kottlowski, F.E., 1965, Road log from Las Cruces to Nutt, *in* Fitzsimmons, J.P., and Lochman-Balk, Christina, eds., 1965, Guidebook of southwestern New Mexico II: New Mexico Geological Society, Sixteenth Field Conference, p. 15-27.

Kelley, V.C., and Silver, Caswell, 1952, Geology of the Caballo Mountains: University of New Mexico Publications in Geology No. 4, 286 p.

*Kottlowski, F.E., 1953, Tertiary-Quaternary sediments of the Rio Grande Valley in southern New Mexico, *in* New Mexico Geological Society Guidebook of southwestern New Mexico, 4th Field Conference, p. 144-148; Road Log, Las Cruces to Caballo, *ibid.*, p. 30-41.

*Seager, W.R., 1975, Geologic map and sections of south half San Diego Mountain quadrangle,

New Mexico: New Mexico Bureau of Mines and Mineral Resources Geologic Map 35, scale 1:24,000.

*Seager, W.R., Hawley, J.W., and Clemons, R.E., 1971, Geology of San Diego Mountain area, Doña Ana County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 97, 38 p.

Seager, W.R., Clemons, R.E., and Hawley, J.W., 1975, Geology of the Sierra Alta Quadrangle, Doña Ana County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 97, 56 p.

Seager, W.R., and Hawley, J.W., 1973, Geology of the Rincon Quadrangle, Doña Ana County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 97, 42 p., scale 1:24,000.

Seager, W.R., Kottlowski, F.E., and Hawley, J.W., 1976, Geology of Doña Ana Mountains, New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 147, 36 p.

*Seager, W.R., and Mack, G.H., 1986, Laramide paleotectonics of southern New Mexico, *in* Peterson, J.A., ed., Paleotectonics and Sedimentation in the Rocky Mountain Region, United States: American Association of Petroleum Geologists Memoir 41, p. 669-685.

Smith, T.J., 1982, Geology of barite in New Mexico, *in* Austin, G.S., compiler, Industrial rocks and minerals of the southwest: New Mexico Bureau of Mines and Mineral Resources Circular 182, p. 61-63.

Walker, 1986, Depositional environments of the Hayner Ranch and Rincon Valley formations (Miocene), Tonuco Uplift, south-central New Mexico: Compass of Sigma Gamma Epsilon, v. 64, no. 1, p. 30-38.

Walker, D., and Mack, G.H., 1985, Tectonics and dispersal of Miocene rift-fill sediments, southern New Mexico: American Association of Petroleum Geologists Bulletin, v. 69, no. 2, p. 314.

SIERRA DE LAS UVAS

General Geology

Sierra de las Uvas is a broad, domed mass of west-dipping Tertiary (Oligocene) rhyolite that occurs northwest of Las Cruces (**figure 1-10**). The volcanic rocks are part of the Bell Top Formation (about 33 m.y. old), including at least five ash-flow tuff sheets and interbedded epiclastic debris. Sierra de las Uvas ash-flow field covers about 3,625 km^2 in northwestern Doña Ana County. Beds form the eastern limb of the northward–plunging Uvas Valley syncline (Good Sight Mountains form the western limb), and mesas are capped by flows, breccias, and sedimentary deposits of the Uvas Andesite, which unconformably overlies the Bell Top

Formation. Stratigraphic sequences crop out on the western limb and axial portions of the Good Sight-Cedar Hills depression. Near the axis, deposits are as thick as 549 m (Seager, 1975).

Several sources for the Uvas Andesite are probably in complexly faulted axial grabens of the Sierra de las Uvas dome, since the number and thickness of the flows decrease away from the dome. Dating of rifting is deciphered from basaltic flows of the Uvas Andesite flowing from a rift fault in the Cedar Hills dated at 26 m.y. Bedding within the fanglomerate deposits that flank the dome indicate that the fanglomerates were deposited contemporaneously with rift faulting. These bedding relations are regional rather than local. Uvas Andesite flows are overlain by the Rincon Valley Formation. Overlying Camp Rice Formation fanglomerates, piedmont gravels, and basin deposits are covered by Quaternary deposits of the ancestral Rio Grande.

Sierra de las Uvas Dome

This dome is the most prominent feature of the Sierra de las Uvas range (**figure 4-3.4**). It formed in the axis of the Good Sight-Cedar Hills depression, where the basaltic shield and older ash-flow tuffs are the thickest (Seager, 1975). The dome is interpreted to be a resurgent dome, with a diameter of 16 km and vertical relief of 610 m. The crest is fractured by a fault that is part of the axial graben (Seager, 1975). Vents occur in the uplift area as well as on the summit. An elliptical aeromagnetic low coincides with the dome. Age of the dome is equivocal, but apparently is post-Uvas Andesite in age, and formed prior to the major rift faults.

Mineral Resources

Volcanic aggregate deposits and pumice for decorative purposes are potential resources.

References

(* reference used in writing above summary)

Clemons, R.E., 1977, Geology of east half Corralitos Ranch quadrangle, New Mexico: New Mexico Bureau of Mines and Mineral Resources Geologic Map 36, scale 1:24,000.

Clemons, R.E., 1976, Geology of west half Corralitos Ranch quadrangle, New Mexico: New Mexico Bureau of Mines and Mineral Resources Geologic Map 44, scale 1:24,000.

Clemons, R.E., 1976, Sierra de las Uvas ash-flow field, south-central New Mexico, *in* Woodward, L.A., and Northrop, S.A., eds., Tectonics and mineral resources of southwestern North America: New Mexico Geological Society Special Publication 6, p. 115-121.

Clemons, R.E., 1977, Geology of west half Corralitos Ranch Quadrangle, New Mexico: New Mexico Bureau of Mines and Mineral Resources Geologic Map 44, scale 1:24,000.

*Clemons, R.E., and Seager, W.R., 1973, Geology of Souse Springs quadrangle, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 100, 31 p.

Elston, W.E., 1957, Geology and mineral resources of Dwyer quadrangle, Grant, Luna, and Sierra Counties, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 38, 78 p.

Hawley, J.W., and Kottlowski, F.E., 1965, Road log from Las Cruces to Nutt, *in* Fitzsimmons, J.P., and Lochman-Balk, Christina, eds., 1965, Guidebook of southwestern New Mexico II: New Mexico Geological Society, Sixteenth Field Conference, p. 15-27.

*James, H.L., and McCall, W.B, 1965, Exit roadlog from Lordsburg to Las Cruces, *in* Fitzsimmons, J.P., and Lochman-Balk, Christina, eds., Guidebook of southwestern New Mexico II: New Mexico Geological Society, 16th Field Conference, p. 86-92.

Kottlowski, F.E., 1953, Tertiary-Quaternary sediments of the Rio Grande Valley in southern New Mexico, *in* New Mexico Geological Society Guidebook of southwestern New Mexico, 4th Field Conference, p. 144-148; Road Log, Las Cruces to Caballo, *ibid.*, p. 30-41.

Seager, W.R., 1973, Resurgent volcano-tectonic depression of Oligocene age, south-central New Mexico: Geological Society of America Bulletin, v. 84, p. 3611-3626.

*Seager, W.R., 1975, Cenozoic tectonic evolution of the Las Cruces area New Mexico: New Mexico Geological Society Guidebook, 26th Field Conference, p. 241-250.

Seager, W.R.,Clemons, R.E., Hawley, J.W., and Kelley, R.E., 1982, Geology of northwest part of Las Cruces 1˚x2˚ sheet, New Mexico: New Mexico Bureau of Mines and Mineral Resources Geologic Map 53, scale 1:125,000.

TORTUGAS MOUNTAIN

General Geology

Tortugas Mountain is a fault-bounded horst block that lies about 5 km southeast of Las Cruces (secs. 23,24; T. 23 S., R. 2 E.). It is composed of bedded rocks trending N. 15-30° W, and dipping about 22° SW; dips steepen locally adjacent to fault zones (**figure 4-4.18**). Limestone, dolomitic limestone shale are the predominant lithologies in the block. Carbonate rocks, thought to be part of the Bursum Formation (King and Kelley, 1980), Hueco Formation (Kottlowski, 1953, 1960), and Magdalena Group (Johnston, 1928), have been extensively dolomitized and silicified; bedding is not discernable and fossils are rare, making correlation difficult (King and Kelley, 1980). Tortugas Mountain block is buried mostly by unconsolildated sediments, mainly semiconsolidated to consolidated deposits of the Camp Rice Formation (Santa Fe Group) and later Recent caliche-cemented slope, fan, and fluvial deposits (Gile and others, 1970; King and Kelley, 1980).

Tortugas Mountain structural trend is an extension of the structural trend of Doña Ana Mountains and Bishop Cap to the northwest and southeast. The triangular outline of the west-tilted

range is a result of the bounding faults which are not exposed and which have been described from water-well and oil-well drilling accounts (King and others, 1971). Within the block, numerous faults and fault zones are exposed that trend north to northwest; offset is equivocal owing to poor exposure and alteration (King and Kelley, 1980). Tortugas fault has been mineralized by fluorite and calcite in a vein up to 3 m wide.

Mineral resources

Fluorite and calcite have been mined from the northeastern side of the block and along the Tortugas fault on the east side of the block (Johnston, 1928; Dunham, 1935; Rothrock and others, 1946) (see McLemore and Sutphin, this volume). Fluorite mines along the Tortugas fault reach depths of 162 m (Rothrock and others, 1946). Hot-spring travertine deposits stained by manganese are present locally within the Camp Rice Formation.

References

(* reference used in writing above summary)

Dunham, K.C., 1935, The geology of the Organ Mountains, with an account of Doña Ana County, New Mexico: New Mexico State Bureau of Mines and Mineral Resources Bulletin 11, 272 p.

Funderberg, D.E., and Roybal, F.E., 1977, Sediment trap efficiency of Tortugas Arroyo near Las Cruces, New Mexico: U.S. Geological Survey Open-File Report 77-0586, 63 p.

Gross, J.T., and Icerman, L., 1983, Subsurface investigations for the area surrounding Tortugas Mountain, Doña Ana County, New Mexico: New Mexico Research and Development Institute, Report 2-67-2238(2), 70 p.

Icerman, L., and Gross, J., 1983, Subsurface investigations for the area surrounding Tortugas Mountain, Dona Ana County, New Mexico: Las Cruces, New Mexico State University Energy Institute, 70 p.

Johnston, W.D., Jr., 1928, Fluorspar in New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 4, p. 61-88.

King, W.E., Hawley, J.W., Taylor, A.M., and Wilson, R.P., 1971, Geology and ground-water resources of central and western Doña Ana County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Hydrologic Report 1, 64 p.

King, W.E., and Kelley, R.E., 1980, Geology and paleontology of Tortugas Mountain, Doña Ana County, New Mexico: New Mexico Geology, v. 2, p. 33-35.

Rothrock, H.E., Johnson, C.H., and Hahn, A.D., 1946, Fluorspar resources of New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 21, 239 p.

WEST POTRILLO MOUNTAINS

(See also Potrillo basalt field and East Potrillo Mountains)

General Geology

During initiation of the Rio Grande Rift, before extrusion of Quaternary basalt, the area of the West and East Potrillo Mountains was faulted, and a north–south–trending horst was formed (Seager, 1987). West Potrillo Mountains horst is covered by olivine alkali basalt and includes several volcanoes that reach elevations of about 1,678 m.

West Portrillo Mountains, part of the broad topographic high that is as much as 244 m above the La Mesa surface, are composed mostly of Quaternary cinder cones and basalt flows less than middle Pleistocene in age [West Potrillo Basalt; 140,000 to 200,000 yrs B.P.] that overlie Tertiary intermediate to silicic rocks. Near the Mexico border, a few exposures of Paleozoic and Cretaceous strata have been disrupted by normal, reverse, and thrust faults, and rumpled into north-trending folds. The east side of the range is marked by a north-trending normal fault, which has had post-bajada movement. The fault may be an extension of the fault, which traverses the Afton-Aden basalt field.

Over 150 vents have been identified within the range, cinder cones being the most abundant type, and flows cover at least 350 mi^2. The cones, which have a spatter rim, are composed predominantly of aggultinated cinder, bedded cinder, and bombs; basaltic dikes occur locally. Mantle and crustal xenoliths have been brought to the surface in lava flows, and contain spinel peridotite, amphibole, and plagioclase. Younger cinder cones are larger and steep-sided; older cinder cones are not as rugged (Hoffer and others, 1991). Quartzose eolian sand covers the basalt flows and the lee sides of the cinder cones.

Malpais Maar

Malpais maar in the southern part of the range, is similar to the Kilbourne, Hunts, and Potrillo maars (**figure 4-4.19**). It formed by eruption of alkalic olivine basalt and has similar stratigraphy. Initial volatile eruptive phases deposited up to 15 m of shattered, brecciated, magmatic material resulting from the mixing of lava and groundwater beneath the surface. A later eruptive phase constructed cinder cones and developed lava flows that are thickest around the bases of the cinder cones. Later, lava fountains produced pyroclastics, eventually constructing a cinder cone and flow complex inside the crater. In the late stages of the maar, olivine-bearing basaltic dikes cut the bedded flows. They are concentrated on the maar rim. Cinder has been quarried from the crater of the maar.

Mt. Riley Maar

Mt. Riley maar, a circular tuff cone about 0.2 km in diameter, is located in the central part of the range. The maar has a rim raised about 20 m above the flat, crater floor. The rim is dissected on the east side, and is breached on the north by intermittent fluvial activity. No faults or joints are present within the maar. Southwest of Mt. Riley, a water well penetrated 87 m of basalt interbedded with sand and gravel.

Mineral Resources

Volcanic cinder deposits are identified resources conservatively estimated at 102 million m^3 (400 million yds^3) (Kilburn and others, 1988). Red and black volcanic cinders have been mined at the southern part of the West Potrillo Mountains since the late 1940s (Gese, *in* Kilburn and others, 1988). Minor amounts of barite in veinlets occur in the Tertiary silicic tuffs on the east side of the range. Quartzose sand may provide a minor resource.

References

(* reference used in writing above summary)

Anthony, E.Y., Barnes, C.G., Chen, W., Hoffer, J.M., Keller, G.R., Marsaglia, K.M., McLemore, V.T., Seeley, J.M., Seward, M.A., Shannon, W.M., and Thomann, W.F., 1991, Examples of modern rift volcanism and Proterozoic anorogenic magmatism--The Potrillo volcanic field of southern New Mexico and the Franklin Mountains of west Texas, *in* Julian, Betsy, and Zidek, Jiri, Field guide to geologic excursions in New Mexico and adjacent areas of Texas and Colorado: New Mexico Bureau of Mines and Mineral Resources Bulletin 137, p. 1-19.

Aubele, J.C., Crumpler, L. S., Loeber, K.N., and Kudo, A.M., 1976, Maare and tuff rings of New Mexico, *in* Woodward, L.A., and Northrop, S.A., eds., Tectonics and mineral resources of southwestern North America: New Mexico Geological Society Special Publication No. 6, p. 109-114.

Austin, G. S., 1994, Pumice mining and environmental concerns in New Mexico: New Mexico Geology, v. 16, p. 1–6.

Austin, G.S., Kottlowski, F.E., and Siemers, W.T., 1982, Industrial minerals of New Mexico in 1981, *in* Austin, G.S., compiler, Industrial rocks and minerals of the southwest: New Mexico Bureau of Mines and Mineral Resources Circular 182, p. 9-16.

Berman, R.G., and Reid, J.B., Jr., 1976, The deep-seated evolution of highly undersaturated basaltic magmas; evidence from kaersutite-gabbro inclusions, West Potrillo Mountains, New Mexico: Eos, American Geophysical Union, Transactions, v. 57, no. 4, p. 354-355.

*Bersch, M.G., 1977, Petrography and geology of the southern West Potrillo Basalt Field, Doña

Ana County, New Mexico: El Paso, University of Texas, unpublished Master's thesis, 60 p.

Gese, D.D., 1985, Mineral resources of the West Potrillo Mountains/Mt. Riley Study Area and the Aden Lava Flow Wilderness Study Area, Doña Ana and Luna Counties, New Mexico: U.S. Bureau of Mines Open-file Report MLA 74-85, 19 p.

Hoffer, J.M., 1969, Volcanic history of the Black Mountain-Santo Tomas basalts, Potrillo volcanics, Doña Ana County, New Mexico, *in* Cordoba, D.A., Wengerd, S.A., and Shomaker, J., eds., Guidebook of the Border Region; Chihuahua and the United States: New Mexico Geological Society, 20th Annual Field Conference, p. 108-114.

*Hoffer, J.M., 1976, Geology of Potrillo Basalt field, south-central New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 149, 30 p.

*Hoffer, J.M., 1976, The Potrillo Basalt field, south-central New Mexico *in* Elston, W.E., and Northrop, S.A., eds., Cenozoic volcanism in southwestern New Mexico: New Mexico Bureau of Mines and Mineral Resources Special Publication 5, p. 89-92.

*Hoffer, J.M., 1986, Subsurface volcanic stratigraphy, southern New Mexico, *in* Hoffer, J.M., ed., Geology of southcentral New Mexico: El Paso Geological Society Field Trip Guidebook, April 11, 1986, p. 119-122.

Hoffer, J.M., Chen, W., McLemore, V.T., and Anthony, E.Y., 1991, Day 2--The Potrillo volcanic field, *in* Julian, Betsy, and Zidek, Jiri, Field guide to geologic excursions in New Mexico and adjacent areas of Texas and Colorado: New Mexico Bureau of Mines and Mineral Resources Bulletin 137, p. 12-19.

Hoffer, J.M., and Ortiz, T.S., 1981, The composition of feldspar megacrysts, Potrillo basalt, West Potrillo Mountains, southern New Mexico, *in* Hoffer, J.M., and Hoffer, R.L., eds., Geology of the border--Southern New Mexico-Northern Chihuahua: El Paso Geological Society, p. 73-78.

Hoffer, J.M., and Sheffield, T.M., 1981, Geology of the West Potrillo Mountains, south-central New Mexico: El Paso Geological Society, Guidebook, p. 79-82.

*James, H.L., and McCall, W.B, 1965, Exit roadlog from Lordsburg to Las Cruces, *in* Fitzsimmons, J.P., and Lochman-Balk, Christina, eds., 1965, Guidebook of southwestern New Mexico II: New Mexico Geological Society, Sixteenth Field Conference, p. 86-92.

Jones, J.L., Kilburn, J.E., Zimbelman, D.R., and Siems, D.F., 1987, Analytical results and sample locality maps of heavy-mineral-concentrate and rock samples from the West Potrillo Mountains/Mt. Riley Wilderness Study Area (030-052), Luna and Doña Ana Counties, New Mexico: U.S. Geological Survey Open-File Report 87-265.

*Kilburn, J.E., Stoeser, D.B., Zimbelman, D.R., Hanna, W.F, and Gese, D.D., 1988, Mineral Resources of the West Potrillo Mountains-Mount Riley and the Aden Lava Flow Wilderness Study Areas, Doña Ana and Luna Counties, New Mexico: U.S. Geological Survey Bulletin 1735, Chapter B, p. B1-B14.

Millican, R.S., 1971, Geology and petrography of the Tertiary Riley-Cox Pluton, Doña Ana County, New Mexico: El Paso, University of Texas, unpublished Master's thesis, 87 p.

Ortiz, T.S., 1979, Megacrysts and mafic and ultramafic inclusions of the southern West Potrillo Basalt Field, Doña Ana County, New Mexico: El Paso, University of Texas, unpublished Master's thesis, 95 p.

*Seager, W.R., 1987, Caldera-like collapse at Kilbourne Hole maar, New Mexico: New Mexico Geology, v. 9, p. 69-73.

MINERAL OCCURRENCES AND MINING DISTRICTS OF THE MIMBRES RESOURCE AREA

The Mimbres Resource Area currently encompasses the largest mining district in the State, --the region near Santa Rita and Piños Altos where open-pit copper mining is taking place. Significant amounts of gold, iron, base metals, silver, fluorspar, tungsten, uranium, and manganese have been produced from other parts of the study area, but Grant County accounts for most of the production (**table 1-2**). In the following descriptions, arranged by county, each mining district is discussed in alphabetical order under the appropriate mountain range. In some cases, a district map shows the locations of the mines, prospects, and occurrences, and accompanying tables show production from each area. Production of mined commodities are reported in dollars, ounces, pounds, short tons, long tons --whatever units that the original records show. Where possible, historical or current photographs of mining activities are provided to give the scope and extent of the operations discussed.

MINERAL OCCURRENCES AND MINING DISTRICTS OF GRANT COUNTY

by

Virginia T. McLemore, NMBMMR,

David M. Sutphin, USGS

Daniel R. Hack, NMBMMR,

and Tim C. Pease, NMBMMR

INTRODUCTION

Prior to 1868, Grant County was part of Doña Ana County. Grant County was established in 1868 and included part of Luna County until 1909 and all of Hidalgo County until 1919. Grant County is the largest metal producing county in New Mexico. Several World-class deposits occur within its borders. In the vicinity of the present-day Santa Rita (or Chino), copper was mined by Native Americans for ornaments, tools, and trade. Since joining the United States in 1846, Grant County has typically led the state in metals production (**Table 5-1.1**).

Three metals mines are in production in the county --Chino (Santa Rita district), Tyrone (Burro Mountains district), and Continental (Fierro-Hanover district). Piños Altos Mine closed in late 1995. The smelter at Hurley and solvent-extraction-electrowinning (SX-EW) plants at Tyrone and Santa Rita are operated by Phelps Dodge Mining Co. Sand and gravel, limestone, and fire clay are also produced in the county (Hatton and others, 1994). Silica flux containing precious metals was produced from the Steeple Rock district in the early 1990s.

ALUM MOUNTAIN

Alum Mountain area contains Alum Mountain district.

Alum Mountain district

Location, Mining History

Alum Mountain mining district (Gila River, Alungen, and Copperas Creek districts), discovered in 1892, is located about 27 km east-northeast of Gila Fluorspar mining district. In 1885, about 1,100 short tons of meerschaum (the common name for the mineral sepiolite) were produced from three shafts (Northrop, 1959; Ratté and others, 1979). In 1945, 3 short tons of ore were produced, containing one oz/short ton Au and 21 oz/short ton Ag from volcanic-epithermal vein deposits (**table 1-3**).

District Geology

The district is situated on Gila Flats, between the northwest-trending Gila Hot Springs graben to the north and Sapillo graben to the south. The rocks in the district are part of the Oligocene volcanic complex of Alum Mountain (30 Ma; Ratté and others, 1979) consisting of

andesitic flows and breccias, pyroclastic and volcanic rocks, and associated small intrusive bodies. Slightly younger latitic and andesitic lava flows of Gila Flat (Ratté and others, 1979) surround the volcanic complex of Alum Mountain.

All hydrothermally altered rocks in the Copperas Creek and Alum Mountain areas belong to the volcanic complex of Alum Mountain (**figure 5-1.1**; Ratté and others, 1979). Altered rocks are confined to andesitic and latitic lava flows, flow breccia, and bedded volcaniclastic and pyroclastic rocks. Most intrusives are dikes and sills a few meters thick. In the southern part of the district, both localized fractures, shallow intrusives, and vents are present. Age of alteration is similar to the age of the host rocks (30 m.y.; Ratté and others, 1979; Marvin and others, 1987). Highly argillized and silicified rocks on Alum Mountain could result from hydrothermal solutions emitted by a larger intrusion beneath the volcanic center and represent solfataric-type alteration commonly associated with volcanic vent activity (Ratté and others, 1979). Acid-sulfate alteration may be indicative of high-sulfide gold deposits at depth (McLemore, 1994d, 1995a; Cox and Singer, 1986; Rye and others, 1992).

Alteration products of hydrothermal water and aluminous minerals in the rocks include quartz, opal, alunite, alum, and a variety of clays (Hayes, 1907). Alum Mountain district is named for the natural alum deposits on Alum Mountain, between Sapillo Creek and the Gila River and on both sides of Alum Canyon.

Mineral Deposits

Alteration caused by descending or ascending meteoric water resulted in widespread solution and redeposition of hydrated aluminum sulfates, mainly halotrichite and alunogen, and created unusually large deposits of these minerals (Ratté and Gaskill, 1975; Ratté and others, 1979). A large body of 90 million short tons of sodic alunite has been defined, as well as significant quantities of microquartz, kaolinite, and iron oxides (**table 5-1.2**). In the late 1970s, a means to exploit the alunite was investigated (Hall, 1978; Ratté and others, 1979). Locally, zones contain 30 percent alunite. In the southern part of the district north and east of Copperas Creek, meerschaum occurs in veins. Locally, gold and silver occur in quartz veins; one sample contained 0.28 oz/short ton Au and 0.36 oz/short ton Ag (Ratté and others, 1979).

Talmage and Wootton (1937) describe the meerschaum deposits as veins in Tertiary igneous rocks, occurring as impure nodules or in blocks up to a meter wide. Beneficiation is needed to separate the meerschaum from crystals of quartz and calcite.

BLACK MOUNTAINS

Black Mountains include the Caprock and Ricolite mining districts.

Caprock Mountain district

Location, Mining History

Caprock Mountain mining district, discovered in 1917, is about 32 km north-northwest of Lordsburg, southeast of the Black Mountains, and along the boundary between Grant and Hidalgo Counties (**figure 5-1.2**). The district lies south of the Gila River on the flanks of Caprock Mountain. Gila Lower Box Wilderness Study Area lies northwest of the district.

A few hundred short tons of manganese ore were produced from epithermal manganese and fluorite veins during World War I (**table 5-1.3**); mines were reopened during the World War II, resulting in limited production. In the 1950s, mines in the district produced intermittently from shallow pits and shafts. In 1959, six men mined about 30 short tons of ore/day from Cliff Roy Mine (Farnham, 1961). Hand-sorted ore and concentrates were sold to buyers in Deming and Socorro. Total production from the district is 1,148 long tons of 21-36 percent Mn and 3,339 long tons of concentrate ore grading 33-35 percent Mn (Farnham, 1961; Dorr, 1965).

District Geology

The oldest rocks in the area (Cliff volcanic center) are Oligocene basaltic breccia and basalt and andesite flows. Gila Conglomerate, which overlies the volcanic rocks, consists of a lower member of consolidated coarse conglomerate (host rock at the Cliff Roy and Ward Mines) and an upper member of poorly consolidated sandstone interbedded with basalt and andesite flows. The sandstone constitutes the hanging wall of the vein at the Consolation Mine; basaltic andesite dated as 21 Ma (Elston and others, 1973, 1983) forms the footwall. Quaternary terrace gravels are predominant in the northwest and southeast; Miocene and Oligocene rhyolite intrusive rocks occur about 1.5 km southwest of the district (Drewes and others, 1985).

In Caprock Mountain district, structures trend N.45°W.; ore-bearing veins along faults and fractures have this trend, especially at Consolation Mine. Other steeply dipping veins trend N.27°W., N.30°W., and N.35°W. Magnitude and sense of displacement along most faults are unknown. The district coincides with a geomagnetic and gravity saddle (see Abrams and Klein, this volume).

Mineral Deposits

Epithermal manganese and fluorite deposits occur along steeply dipping fault and fracture zones in volcanic Gila Conglomerate (**figure 5-1.2.**; Farnham, 1961). At Cliff Roy, the largest deposit, steeply dipping veins are 0.5-1.8m wide and strike N.9°W. Ore minerals (psilomelane and minor pyrolusite) occur in disconnected, lenticular shoots that range in length from a few

meters to 30m and grade upward into banded travertine. In the ore shoots, manganese minerals occur as irregular strands, bunches, and coatings on breccia fragments. Chalcedony, manganiferous calcite, and some gypsum are gangue minerals. Psilomelane typically contains small inclusions of milky chalcedony. A sample assayed 45 percent Mn, 3 percent SiO_2, and 0.15 percent P (Wells, 1918).

The Cliff Roy deposit extends for 37m along a fault trending N.45° W.; it is up to 4m wide. Other deposits similar to the Cliff Roy are smaller. At Black Bob deposit, brecciated basalt is the host rock. Argillic alteration and iron staining characterize both deposits (Pradhan and Singh, 1960; Gillerman, 1964). Fluorite is common locally. In the 1950s, Consolation Mine yielded about 10,000 short tons of 8-10 percent Mn (Gillerman, 1964; Ryan, 1985; Richter and Lawrence, 1983; Richter and others, 1988). Geochemical anomalies in stream-sediment samples include Ag, Co, Cu, Mn, and Y and spotty La, Sn, Th, and Ti (Hassemer and Marsh, unpublished data, 1995). Cliff Roy, Consolation, and Black Bob manganese deposits are small tonnage, low grade, and inaccessible.

Ricolite district

Location, Mining History

Ricolite mining district straddles the Gila River in the Black Mountains; most of the district lies north of the river, extending to Smith Canyon and Tank Draw. The district includes fluorite and manganese mines and prospects on the south bank of the river (**table 5-1.4**). Ash Creek Canyon (Ricolite Gulch) ricolite deposit is located about 8 km north-northwest of Redrock (**figure 5-1.3**). Ricolite, a banded, light to dark green talc-serpentinite used for ornamental stone and in building interiors (Gillerman, 1964), is a mixture of serpentine talc and small chlorite flakes (McMackin, 1979).

Ricolite and massive serpentine were first quarried in Ash Creek Canyon the 1880s. In about 1888, a shipment was sent to Chicago where it was used for wainscoting (Talmadge and Wootton, 1937). Shipments totalling 90 short tons were made in 1946 (Benjovsky, 1946). McMackin (1979) describes modern collecting of ricolite for lapidary pieces.

Fluorite production south of the Gila River has been significant. Hope prospect shipped 74 short tons of fluorite ore in 1942, and Great Eagle Mine shipped 15,215 short tons of ore from 1911 to 1944. Allied Chemical calculated 1975 reserves at 195,324,000 short tons ore at 43.1 percent CaF_2 (McAnulty, 1978).

Manganese production was localized in the northwest corner of the district. At Black Eagle Mine, 36 long tons of ore with 24.9 percent contained manganese were produced in 1942, and 405 long tons of ore averaging 19.5 percent Mn were produced in 1953-1954 (Farnham, 1961).

District Geology

Rocks near Ash Creek Canyon are Proterozoic granite and diabase in which tabular xenoliths of talc serpentinite associated with serpentine marble and massive serpentinite are present (Kottlowski, 1987). Prior to the metamorphism of the material in the xenoliths, Ash Creek Group rocks were interlayered units of siliceous dolomite and argillaceous limestone (Hewitt, 1959). Metamorphism initially was low-grade and regional, but was followed by several thermal metamorphic events during intrusion of anorthosite, diabase, or granite. Hewitt (1959) showed that metamorphism was greatest next to the diabase. Formation of talc or serpentine results from hydrothermal alteration of quartz and dolomite and depends on the magnesium content of the original sedimentary rock (Gillerman, 1964). Locally, talc-rich rocks up to a meter thick predominate over serpentine.

Mineral Deposits

Ricolite occurs in the steeply dipping, tabular xenoliths of serpentine-carbonate rocks in the metamorphic granite and metadiabase of the Ash Creek Group (Hewitt, 1959). Xenoliths are composed of several varieties of hornfels and serpentinite. The largest xenolith is about 1.6 km long; smaller xenoliths are scattered. Fractures are filled with calcite or quartz, and cross-fiber veins of asbestiform serpentine (chrysotile) are present (Kottlowski, 1987). Hewitt (1959) describes the ricolite as fine-grained talc serpentinite that has undisturbed banding similar to that of finely bedded sedimentary rocks. Bands range from 0.1 mm to about 5 cm thick; average thickness is less than one cm. The ricolite ranges in color from light greenish yellow to very dark green, but shades of red, yellow, blue, and brown occur locally. Chlorite, calcite, and quartz occur in the serpentinite, and mottled and massive canary-yellow serpentine is associated with the ricolite (Gillerman, 1968).

Productive fluorite deposits south of the Gila River are characterized by colorless to dark-green fluorite; most contains chert as an impurity (**table 5-1.4**). At White Eagle Mine, fluorite layers alternate with chert layers in a vertical shear zone. At Hope prospect, a pit exposes a vein of fluorite and chert breccia (Hewitt, 1959). North of the Gila River near Tank Draw, fluorite occurs in shattered and brecciated zones in Precambrian granite at the Blue Eagle and Jackpot prospects (Gillerman, 1964; Williams, 1966). In Section 22 just east of Blue Eagle prospect, narrow fluorite veins occur in Precambrian granite along N.40°-50°W.- trending, Tertiary rhyolite dikes. At Great Eagle Mine on the south bank of the Gila River in the southeast corner of the district, Precambrian granite occurs within a shear zone up to 12m wide that trends N.30°-40°W. and dips vertically (Hewitt, 1959).

Precambrian granite is in contact with Tertiary volcanic rocks and Gila Conglomerate in the northwest corner of the district at the Black Eagle Mine in Tank Draw. Veins and pods of manganese (pyrolusite, psilomelane, manganiferous calcite, and wad) occurs in a vein up to 2.5m thick along a northwest-striking fault (Farnham, 1961; Gillerman, 1964). Extensively kaolinized microcline is found in the granite enclosed by the vein, as well as in the granite footwall (Hewitt, 1959). At Simpson prospect northeast of Great Eagle Mine, psilomelane and pyrolusite occur with fluorite as nodules and veins (Gillerman, 1964).

Porphyry copper exploration north of Ash Creek Canyon was conducted by Freeport Sulphur Company in 1960 (**figure 5-1.3**). Four drillholes up to 397m deep encountered only minor pyrite and oxidized pyrite in two holes; no evidence of sulphides or hypogene mineralization was found (Gillerman, 1964).

A small magnetite deposit is located just north of the ricolite prospects. Magnetite-rich bands about 0.5m in width occur in serpentine within xenoliths of metamorphosed Precambrian granite. Magnetite locally constitutes 90 percent of the rock, but the deposit is small and inaccessible (Kelley, 1949; Gillerman, 1964).

In Smith Canyon about 1.5 km west of the ricolite prospects, replacement magnesite-quartz-dolomite beds within dolomite occur as lenses as much as 18m wide and 23m thick. No production took place at this location (Kottlowski, 1977).

At Blue Eagle Fluorspar Mine, located about 1.5 km northwest of Great Eagle Mine, north-northwest-trending radioactive fluorspar veins occur within Precambrian granite and diabase. Radioactivity is about 2 times background; uranium and thorium are believed to be the radioactive elements. No production took place at this location (Hewitt, 1959; unpublished data, NMBMMR).

BIG AND LITTLE BURRO MOUNTAINS

The Big and Little Burro Mountains include the Black Hawk, Bound Ranch, Burro Mountains, Cora Miller, Malone, Telegraph, and White Signal mining districts.

Black Hawk district

Location, Mining History

Black Hawk (Bullard Peak) mining district is about 55 km west of Silver City in the northern Burro Mountains. The district includes all mines and prospect pits within 13 km south and east of Bullard Peak. Mining began in the district in 1881 with the discovery of the unique silver-nickel-cobalt deposits at the Alhambra Mine (Gillerman and Whitebread, 1956); other deposits were discovered later. Mining continued until 1893 when declining silver prices and depletion of rich silver ore closed the mines. In 1917, Black Hawk Mine was dewatered, but had

no recorded production. In 1920, pitchblende (uraninite) was recognized on mine dumps in the area, and in 1949 the area became of interest as a possible source of uranium, nickel, and cobalt.

Types of deposits found in the Black Hawk mining district include Laramide vein, tungsten placer, and pegmatite deposits (see Sutphin, this volume). Total metal production from 1881-1960 is estimated to be 3,000 lbs Cu, 1,000 oz Au, 1,286,000 oz Ag, and 4,000 lbs Pb (**table 5-1.5**). In addition, 10,542 short tons of 2.7-71 percent WO_3 (tungsten) ore (Richter and Lawrence, 1983; Dale and McKinney, 1959) and 615 short tons of fluorspar ore were produced (Williams, 1966; McAnulty, 1978).

District Geology

In Black Hawk mining district, exposed rocks of the Bullard Peak series of Hewitt (1959) include quartzite, amphibolite, migmatite, and various types of schist and gneiss (**figure 5-1.4**; Hewitt, 1959; Gillerman, 1964). These rocks are intruded by Precambrian quartz diorite gneiss, which is the predominant rock type in the area, and part of the Burro Mountains batholith (Gillerman, 1964). The gneiss, which contains 35 ppm Co and 23 ppm Ni (Gerwe and Norman, 1985), is intruded by 73 Ma (Hedlund, 1985a) Twin Peaks monzonite porphyry. Twin Peaks monzonite occurs in dikes and irregular masses in the northern portion of the district (Gillerman, 1964). It contains 20 ppm Co and 11 ppm Ni (Gerwe and Norman, 1985) and is associated with mineralized veins. To the north, metamorphic and igneous rocks are overlain by Cretaceous quartzite and Tertiary rhyolite (Gillerman, 1964). Two prominent fault systems trend slightly east of north (Gillerman, 1964) and have numerous splays that trend northeast or northwest.

Mineral Deposits

Nickel-cobalt-silver deposits of the Black Hawk mining district are unusual and of special interest. Although similar deposits are described worldwide (Cobalt and Great Bear Lake in Canada and Joachimstahl in the former Czechoslovakia; Gillerman and Whitebread, 1956), only a few known deposits have nickel-cobalt-silver ore with uranium in carbonate gangue (Gillerman, 1964).

In Black Hawk district, the mineral deposits are simple fissure veins, mostly occurring in quartz diorite gneiss near bodies of monzonite porphyry (**figure 5-1.4**). Four mineral assemblages occur: (1) silver-argentite-uraninite- niccolite- rammeisbergite, (2) silver-rammeisbergite-gersdorffite-nickel skutterudite, (3) chalcopyrite-tennantite-galena-sphalerite, and (4) acanthite-jalpaite-pearceite- covellite (Von Bargen, 1979, 1993). Pitchblende is found with minor pyrite, chalcopyrite, galena, and sphalerite. Additional minerals are millerite, erythrite, annabergite, barite, manganocalcite, and various nickel and cobalt sulfarsenides and arsenides (Gillerman, 1964; Von Bargen, 1979, 1993). Deposits are most plentiful in an area 1.5

km x 5 km on the southwest side of Twin Peak stock (Gillerman, 1964). Veins can be traced for more than 1,600m laterally and as much as 965m vertically. Width of the veins varies from 1.5m to 45.0 m, but may reach 15m in width where they cut quartz-diorite gneiss. Veins are recognized by brown-stained carbonate filling such as calcite, dolomite, siderite, and ankerite (Gillerman, 1964). Quartz is rare, occurring as a dull yellow-green chert or chalcedony. Mineralization occurred about 65 Ma at temperatures of 290°C-410°C (Gerwe, 1986). Low fluid-inclusion salinities (less than 2 eq. wt. percent NaCl) suggest that water in the system was meteoric (Gerwe, 1986; Gerwe and Norman, 1985).

Native silver occurs in the central part of Laramide veins and nickel- and cobalt-bearing minerals (mostly nickel skutterudite) is present on vein margins (Gillerman, 1968). Uraninite is typically found in the outermost zones associated with nickel- and cobalt-bearing minerals. According to Naumov and others (1971), calcite, dolomite, ankerite, and siderite form in sequence, owing to increased carbon dioxide in mineralizing solutions at constant temperatures. Kissin (1988) suggests that vein deposits having the five-element suite silver-nickel-cobalt-arsenic-bismuth, such as those in the Black Hawk area, indicate non-magmatic epigenetic mineralization. Nickel and cobalt concentrations in the Black Hawk district are of large areal extent; they probably originated by leaching of Precambrian quartz-diorite gneiss (Gerwe and Norman, 1985; Gerwe, 1986; Von Bargen, 1979).

Gillerman and Whitebread (1956) reported that in May 1952, three 300-m diamond drill holes were positioned to intersect Black Hawk vein. The core was checked for radioactivity, but no anomalous readings were made. In 1982, Black Hawk Mine was exploited for silver.

Tungsten deposits also occur south and east of Bullard Peak (**table 5-1.6**) and scheelite placer and lode deposits were located using ultraviolet lamps (Dale and McKinney, 1959). Deposits are located near Precambrian pegmatite and amphibolite (Gillerman, 1964). Scheelite seams are associated with pegmatite dikes (Dale and McKinney, 1959) or along faults (Gillerman, 1964). When found associated with quartz veins, scheelite commonly occurs at the vein margin or as disseminations in the country rock (Gillerman, 1964).

Bound Ranch district

Location, Mining History

Bound Ranch (Langford Hills) mining district is in the southern Burro Mountains, about 26 km south of the Tyrone porphyry-copper deposit and 6.4 km southeast of Gold Hill mining district. Fluorite and tungsten were produced from this district beginning in the early 1900s (**table 1-5**; **table 1-7**). A few deposits were worked for fluorspar and gold, but the gold content was too low to sustain mining operations (**table 5-1.7**). American Mine operated during World

War I, in the early 1930s, during World War II, and sporadically thereafter (Gillerman, 1964; Williams, 1966). The deposit was worked mainly for fluorspar; gold content was low. Double Strike (Valley Spar) deposit was opened initially as a gold mine in the early 1920s, but it was mined for fluorite during World War II. Continental deposit produced fluorspar during World War II. Total production in the district is 3,230 short tons fluorite and 4,150 short tons WO_3 from Hillside, Alpha, and Bluebird Mines (Dale and McKinney, 1959; Hobbs, 1965).

District Geology

Bound Ranch district is comprised mostly of Precambrian granite. Lenses of Precambrian schist, amphibolite, quartzite and other metamorphic rocks are common in the granite as are Precambrian aplite, pegmatite, and diabase dikes. Northeast-trending faults are common and are marked by mineralized zones.

Mineral Deposits

Mineral deposits in the Bound Ranch district are mainly fluorspar stringers and veins in Precambrian granite (Johnston, 1928; Rothrock and others, 1946; Gillerman, 1951, 1968). Fluorite is predominately green or purple, but also white, violet, and yellow (Gillerman, 1951). Cube and octahedron forms are the most common crystal forms, but dodecahedron forms modify the cubic form at the American, Double Strike, and JAP Ranch deposits. At Double Strike, fluorite cubes modified by dodecahedron, tetrahedron, and hexoctahedron forms occur (Gillerman, 1951). Massive texture is common; columnar or granular textures are localized. In the vicinity of the Burro Mountains, violet fluorite usually represents the last stage in a three-stage mineralization process (Rothrock and others, 1946; Gillerman, 1951). Quartz is the most common mineral associated with fluorite; minor calcite, pyrite, chrysocolla, turquoise, malachite, hematite, limonite, native gold, silver, manganese oxide, halloysite, autunite, and uranophane are present.

Double Strike, Windmill, American, Continental, and JAP Ranch deposits are localized along or near the Malone fault. The deposits are mineralogically similar (Gillerman, 1951). American, Continental, and Double Strike deposits have been mined for both fluorite and gold, and have numerous shafts, pits, and trenches. JAP Ranch and Windmill deposits are small and have been explored only by shallow workings.

At Continental deposit, fluorite occurs along a prominent fault for 975m and is associated with silicified fault gouge and breccia (Rothrock and others, 1946; Gillerman, 1951). The north-trending fault dips 60°-85°E and cuts Precambrian gneiss, lenses of Precambrian schist and quartzite, and middle Tertiary volcanic rocks. Fluorite is found in both the Precambrian and volcanic rocks. Fluorite is commonly clear green to yellow-green, coarsely crystalline, and cubic, with etched crystal faces. The only mineral associated with fluorite is quartz, although scheelite is

present in a quartz vein about 183m west of the fluorspar vein.

The American deposit occurs in vein and breccia zones along faults that splay from the southwestern side of the Malone fault within Precambrian granite (Rothrock, and others, 1946; Gillerman, 1951). The granite is intruded by pegmatite, aplite, diabase, and rhyolite dikes. Fluorite is most abundant within about 90-213 m, from the Malone fault. Veins are as much as one meter wide; breccia zones are up to 9m wide. Green, nearly pure, coarsely crystalline fluorite occurs in veins and as cement in the breccia. A 50-cm chip sample taken from a cut 14m northeast of the main shaft assayed 47 percent CaF_2 (Williams, 1966).

At Double Strike deposit, fluorite occurs in three silicified breccia zones that range from 0.3m to 1.2m wide in faulted Precambrian granite (Rothrock and others, 1946; Gillerman, 1951). Fluorite occurs within breccia or veins that cut the silicified fault gouge. Two fluorite types were deposited —an earlier purple and dark-green fluorite, and a later pale green and white fluorite.

At JAP Ranch deposit, small amounts of fluorite are present in fissure veinlets along a northeast-trending fault. Veinlets range up to 0.3m wide and crop out for 24 m. The fluorite is pale green and cubic and dodecahedral in form (Williams, 1966).

Bounds, Fence Line, Grandview, and Grant County deposits are located 4-6 km southwest of Malone fault (**table 5-1.7**; Rothrock and others, 1946; Gillerman, 1951). At the Bounds deposit, coarsely crystalline green fluorite occurs in a vein 0.6-1.8m wide and 91m long within granite; smaller veins are also present. At Grandview deposit, clear green, coarsely crystalline fluorite occurs in a 0.6-m-wide vein; disseminated fluorite occurs in highly brecciated fractures in granite (Williams, 1966). Fence Line and Grant County deposits occur along the same mineralized zone. At the Grant County deposits, four subparallel veins are exposed in several trenches.

Langford deposit, less than 4 km south of the Grandview deposits, contains uranium minerals associated with the fluorite. The fluorite occurs within granite in a 1.5-m-wide silicified breccia zone that strikes N.15°W. and dips 62°NE (Gillerman, 1951). Mineralization consists of dark purple, fine-grained fluorite encrustations and veinlets less than 2 cm thick within breccia. Uranium minerals are concentrated near the dark purple fluorite, and possibly within it (Gillerman, 1951).

Low-grade scheelite and wolframite ore is scattered within narrow quartz veins in several deposits. One shipment of 3.3 short tons of 60 percent WO_3 was reported from the Hillside and Alpha Mines (Hobbs, 1965). Garnet, epidote, hornblende, calcite, and quartz are found associated with scheelite at Alpha Mine (Gillerman, 1964).

Burro Mountains district

Location, Mining History

Burro Mountains mining district includes parts of the Big Burro and Little Burro Mountains (**figure 4-1**). Copper minerals were first discovered in the district about 600 AD when Indians mined turquoise for jewelry and trade. In the early 1860s, mining claims were filed. In about 1880, exploration in western Grant County resulted in gold, silver, lead, and copper deposits. Mining of rich silver ore continued until 1885. In 1885, a stamp mill was erected on the Gila River, and in 1903 a leaching plant was constructed near the mill (Hewitt, 1959). In 1909, Phelps Dodge Mining Co. consolidated 150 mining companies that were mining by numerous underground operations in the area of the Tyrone body. During this time, several high-grade areas of 2-3 percent Cu were mined out (**table 5-1.8**). In 1921, underground mining ceased. From 1948 to the 1950s, a drilling program was employed to define the Tyrone orebody. Overburden stripping began in 1967; open-pit mining commenced in 1969 and a 272-year-old underground mine was consumed by the pit.

Mineral deposits in the district are dominated by the Tyrone porphyry-copper deposit, but deposits of precious- and base-metal fluorite, uranium, clay, and dimension stone also occur in the district (Gillerman, 1964; Richter and Lawrence, 1983; Hedlund, 1985a). Currently, Tyrone uses SX-EW technology to annually produce 148-150 million pounds of copper. Recovery procedures have changed from sulfide concentration to heap leaching. Future advances in bio-leaching technology may open huge tonnages of ore to further copper recovery (Bruce Kennedy, Phelps Dodge Mining Co., oral commun., April 1994).

Total production from the district amounts to more than 5.24 billion lbs Cu, 50,000 oz Au, 10 million oz Ag, 200,000 lbs Pb, and 300,000 lbs Zn. About 300 million short tons of ore grading 0.81percent Cu were processed by the concentrator from 1969 to 1992. About 425 million short tons of ore grading 0.35 percent Cu have been leached (R. J. Stegen, Phelps Dodge Mining Co., written communication, October 3, 1994). Reserves are estimated as 230.2 million short tons of leach ore grading 0.35 percent Cu (Robert M. North, Phelps Dodge Mining Company, written commun., October, 1995).

While Tyrone is the largest producer, it is not the only producing mine in the district (**table 5-1.8**; **table 5-1.9**). Contact Mine has had significant production (Gillerman, 1964). The 225-ft Contact shaft was sunk on the Contact vein hoping to find gold and silver, but it was worked in 1939 for base metals. That year, 150 short tons of ore were shipped. Between 1942 and 1944, 2,121 short tons of ore containing up to 7 percent combined Pb and Zn, 2 oz/short ton Ag, 0.02- 0.03 oz/short ton Au, and 0.25 percent Cu were shipped. In 1943, Contact Mine was

worked for manganese, and 140 short tons of ore averaging 20 percent Mn were shipped. Turquoise has been produced from the district (Zalinski, 1907), as well as 172,539 short tons of fluorite and 30 lbs of U_3O_8.

District Geology

Little Burro Mountains on the northeast side of the Mangas Valley are an isolated range of hills 46 km long and 5 km wide that trend northwest along a northeast-tilted fault block on the west side of the Mangas fault. The mountains are composed of Precambrian granite and Cretaceous sedimentary rock intruded by andesitic and rhyolitic rocks, and are overlain by Tertiary volcanic flows (Kolesaar, 1970,1982; DuHamel and others, 1995). Big Burro Mountains on the southwest of Mangas Valley are composed of the Burro Mountains batholith, a body of Precambrian granite (Burro Mountains granite) emplaced into schists, amphibolites, and quartzites of the Bullard Peak series of Hewitt (1959)(**figure 4-1**). Burro Mountains granite is intruded by Precambrian diabase dikes, dikes and plugs of rhyolite and other rock types and ages, and the Tyrone stock, a quartz monzodiorite porphyry laccolith dated at 53 to 57 Ma (DuHamel and others, 1995). The elliptical laccolith is 16 km long and 10 km wide (Kolessar, 1982).

The largest part of Tyrone stock is made up of medium-grained, massive quartz monzodiorite (Hedlund, 1985a; Hedlund, 1978g,j). The remainder of the stock is light-gray to light brownish-gray quartz monzonite porphyry, pinkish-gray aplite, and light-gray porphyritic quartz monzonite dikes as much as 35m wide. Paleozoic and Mesozoic rocks are absent, with the exception of Mesozoic units in the Little Burro Mountains (Hedlund, 1985a).

Gillerman (1970) notes that structural features are most important in localizing the ore bodies. Northeast-trending faults, fractures, and shear zones are the prominent structures in and around the district. Five major faults have been recognized--Osmer, Bismuth-Foster-Beaumont, Austin-Amazon, Burro Chief, and Sprouse-Copeland. Other major faults, such as the Mangas and Walnut Creek faults, trend northwesterly. Mangas fault is an eastern boundary fault for the Big Burro Mountain block; Walnut Creek fault lies within the block. Some faults are intruded by rhyolite and quartz monzodiorite porphyry dikes. Fault movement has resulted in brecciation of the dikes.

Mineral Deposits

Mineral deposits in the Little Burro Mountains are divided geographically by deposit type (**table 5-1.9**). Deposits in the central part of the Little Burro Mountains contain gold, silver, copper, lead, and zinc in fractures and faults, and consist of gold, galena, sphalerite, chalcopyrite, pyrite, probable argentite, and their oxidation products. Pyrolusite and psilomelane are common; in 1943, the Contact Mine was mined for manganese (Farnham, 1961). Precambrian skarn

deposits containing scheelite are found at the contact of the Burro Mountains granite and hornblende schist of the Bullard Peak series of Hewitt (1959) (Hedlund, 1985a). Deposits of fluorite, uranium, clay, and dimension stone also occur in the Little Burro Mountains.

Bostonian and Montezuma groups of claims in the eastern Burro Mountains district are typical of copper deposits in the southern part of the mountains (Gillerman, 1964; Hedlund, 1985a). Host rocks for the numerous shafts, pits, and adits are intensely altered Early Tertiary monzonite porphyry and quartz monzonite porphyry (possibly part of the Tyrone stock). Northeast-striking Laramide veins are vertical to steeply dipping. The veins are narrow, and can be traced for no more than a few hundred meters. Deeper shafts in the area are sunk along, or close to, the Mangas fault. Quartz-molybdenite veins (pyrite and chalcopyrite) occur at the northwestern margin of the Tyrone stock, and quartz-specularite veins occur at the eastern end (Hedlund, 1985a). Some veins have siliceous and ferruginous cappings, owing to extensive oxidation (weathering). Where erosion has been rapid, veins are relatively unoxidized.

Contact group deposits (a group of gold-silver-base metals deposits in the central Little Burro Mountains) exploit quartz-filled fissure veins along north-northeast-trending faults (Gillerman, 1964). Development consists of the Contact and Virtue shafts and Virtue tunnel along the 2-m wide Contact vein. Contact vein strikes N.60°E. and dips 70°SE at Virtue shaft, and strikes N.20°E. and dips 75°SE at Contact shaft. In 1944, ratio of gold to silver at Contact Mine was 4:1; in 1960, it was 3.5:1. The vein consists of quartz with minor pyrite and chalcopyrite, and abundant psilomelane, pyrolusite, argentiferous galena, and sphalerite. The vein lies along the contact between granite and andesite, and silicified fractures are seen along the vein.

The most important deposit is the Tyrone porphyry copper deposit (**table 5-1.9**; **table 5-1.10**). Tyrone ore body is a chalcocite blanket (or manto) developed over Tyrone stock (Kolessar, 1970, 1982; DuHamel and others, 1995). At Tyrone Mine, the stock is mostly porphyritic quartz monzodiorite with abundant quartz, oligoclase, and sporadic chloritized biotite (Kolessar, 1970, 1982). The mineralized portion shows pronounced potassic metasomatism and sericitic alteration. Fine-grained quartz monzonite dikes intrude the stock and the surrounding Precambrian granite. The main ore body consists of a supergene blanket containing erratic chalcocite mineralization varying from a few meters to over 90m thick. Two main episodes of supergene enrichment occurred at 44-47 Ma and at 19 Ma, followed by a third weak, but younger, supergene event (DuHamel and others, 1995; Cook, 1993). Ore in the oxidized zone consists predominantly of chrysocolla. Other ore minerals (malachite, azurite, cuprite, tenorite, native copper, turquoise, minor torbernite, and autunite) occur in kaolinized areas. Most of the minerals occur as disseminations and fracture fillings within the stock and Precambrian granite (Hedlund,

1985a). The supergene cap consists of chalcocite and minor covellite, which replace primary pyrite, chalcopyrite, and sphalerite. Hypogene minerals are pyrite, chalcopyrite, sphalerite, galena, and trace molybdenite and bornite. Fluorite is found locally, and alunite is common. Ore is low-grade, but several localized high-grade areas average three percent Cu.

Breccia ore bodies are described as intrusive breccia (Paige, 1922) and hydrothermal breccia (DuHamel and others, 1995). They consist of fragments of granite and quartz monzonite porphyry up to 120m in diameter. Breccia deposits are low-grade, but contain supergene mineralization (DuHamel and others, 1995). Breccia pipes are found within the Tyrone stock and granitic rocks (Hedlund, 1985a).

Cora Miller district

Location, Mining History

Cora Miller district is northeast of the Telegraph district in the Mangas Creek area, northern Big Burro Mountains (**figure 5-1.5**). The district includes Cora Miller Mine (volcanic-epithermal vein and epithermal manganese deposits) on the south side of Mangas Creek. The silver mine was worked in the 1880s, producing considerable high-grade silver ore from fissure veins (Lindgren and others, 1910; Gillerman, 1964). Copper, gold, and lead were present in the silver ore. Since the 1880s, the mine has been abandoned. Mine workings consist of a 54-m shaft inclined at 85°, an upper adit at the shaft collar level, a lower adit at 23m depth, and a working level at 54m depth (Gillerman, 1964). Numerous open cuts, shallow shafts, and stopes explored the vein for 243 m. Shallow workings at the mine site may have produced manganese in 1920 and in 1940-1942 (Wargo, 1959; Farnham, 1961). Production figures are not known.

District Geology

Rocks in the district are Tertiary rhyolite, flow breccia, and tuff with interbedded andesite and latite porphyry, and thin sandstone and conglomerate beds. The mine is along the northern ring-fracture zone of the Schoolhouse Mountain caldera (Finnell, 1987).

Mineral Deposits

At Cora Miller Mine, silver occurs in a volcanic-epithermal quartz fissure vein in Tertiary rhyolite ash-flow tuff. The vein strikes N.70°-75°E. and, east of the mine, dips beneath the floodplain alluvium of Mangas Creek. The vein ranges in width from 1.2m to 1.5m at the mine, but narrows to less than 0.3m at the farthest prospect pit. Gillerman (1964) notes that a small cross fault cuts the vein about 55m west of the shaft; a small offset was observed in the adit about 21m east of the shaft. Quartz is the principal gangue mineral; malachite and gold are found in dump samples. No information is available on the minerals that were mined.

Manganese-bearing vein deposits occur also in a breccia zone exposed in shallow workings (Wargo,1959). Crushed breccia fragments within the fracture zone have been cemented and partially replaced by black manganese oxides. Vein quartz is present locally.

Malone district

Location, Mining History

Malone mining district lies in the southwestern Burro Mountains along the Malone fault. John B. Malone discovered gold in the area in 1884 after years of placer mining in nearby Gold Gulch and Thompson Canyon (Gillerman, 1964). In 1904, when gravels in many local gulches were worked for placer gold, bedrock discoveries were made west of the old Malone Mine. Production prior to 1925 totaled about $250,000 in gold and minor silver, mostly before 1900. Total production after 1925 was no more than $50,000. In the 1930s, renewed interest in the area led to new mining ventures and extensions to some older workings. From the 1940s until at least 1964, mining was intermittent. In 1961, Albert A. Leach of Lordsburg owned 13 unpatented claims covering most of the district (Gillerman, 1964). Total production from Laramide veins and placer gold deposits is about 12,000 oz Au, more than 10,000 oz Ag, 408 short tons of fluorite, and minor copper, lead and zinc
(**table 5-1.11**).

District Geology

Precambrian Burro Mountains granite crops out on the south side of Malone fault, and Tertiary rhyolite tuff, perlite, and agglomerate are present on the north side. Malone fault strikes N.20°W. and dips 70°NE., and marks the western edge of Knight Peak graben (**figure 4-1.3**). Numerous fractures cut the granite adjacent to the fault, but the fault itself is not mineralized (Gillerman, 1964). Fractures trend mostly N.45°-85°W. The Patanka vein, which cuts the granite, strikes N.35°E. and dips steeply southeast. The granite adjacent to the veins shows evidence of sericitic, kaolinitic, and hematitic alteration.

Mineral Deposits

Fractures that cut the Burro Mountains granite near the Malone fault are mineralized for lateral distances along the fractures of as much as 300 m. Fracture fillings are gold-bearing quartz and pyrite veins with minor chalcopyrite, argentiferous galena, and sphalerite (Gillerman, 1964). Gold in the veins can only be detected by geochemical analysis. The mineralization is shallow and none of the mines in the area are greater than 30m deep.

The shaft at Malone Mine on the Esmeralda vein, the source of most district production in the 1880s and 1890s, is near the granite-rhyolite contact. Hillcrest vein, which strikes N.85°W. and dips vertically, is located 550m north of the Esmeralda vein. At this claim, a 30-m shaft leads

to drifts that follow the vein. Other shafts, pits, and adits in the area explore the Barranca vein, which strikes N.40°W., dips 70°NE, and offsets the Malone fault. At the Barranca vein, the footwall is granite and the hanging wall is rhyolite (Gillerman, 1964).

Telegraph district

Location, Mining History

Telegraph mining district is located in the northern Big Burro Mountains and contains a diverse range of mineral deposits (**table 5-1.12**; **table 5-1.13**). Small Laramide vein and volcanic-epithermal deposits of precious- and base-metals, fluorite, manganese, uranium, and other commodities have been discovered and mined in the district. Total known production amounts to 1,700 lbs Cu, 1 oz Au, 1,350 oz Ag, 37,800 lbs Pb, minor Zn, 220 long tons of manganese ore, and 16,603 short tons of fluorite. Stratabound uranium deposits occur in the Wild Horse Mesa area.

Of the several small mines and prospects in the district, Telegraph Mine is the best known. By 1905, the small Telegraph ore body had been depleted and the mining camp abandoned (Lindgren and others, 1910). No record of the mineralogy or production from the Telegraph Mine exists (Hewitt, 1959).

From 1947 to 1953, Purple Heart Mine produced 1,288 short tons and Hummingbird Mine produced 615 short tons of fluorite ore (Williams, 1966). Minor manganese production occurred in the district, with Black Tower claim producing 205 long tons of ore with 41-42 percent contained manganese from 1954 to 1957. Hillside Mine produced 15 long tons of ore with 24.6 percent contained manganese from 1952 to 1953. In 1941, Slate Creek Mine produced 10 short tons of ore containing 0.36 oz gold, 100 oz silver, 40 lbs copper, and 2,103 lbs lead (unpublished data, NMBMMR).

District Geology

The northern Burro Mountains are composed mostly of granite, quartz diorite, and associated Precambrian igneous rocks of the Burro Mountains batholith. Cretaceous sedimentary and volcanic rocks overlie Precambrian rocks in the northern part of the district. Gila Conglomerate and Recent gravels fill the valleys.

Quartz diorite that crops out extensively in the northern Big Burro Mountains is porphyritic, distinctly foliated, and tan-weathering. It forms rounded, knobby outcrops owing to eroded feldspar phenocrysts (Gillerman, 1964, 1970). The southern boundary of School House Mountain caldera is present in the northern part of the district (Wahl, 1980). Radial and ring-fracture faults that control mineralization are common.

Mineral Deposits

The abandoned Telegraph Mine is located in an area where Beartooth Quartzite and Burro Mountains granite are cut by northwest-trending faults (Hewitt, 1959). A mineralized fissure vein exposed on one hilltop strikes N.28°E. and dips 64°SE.; it is less than 35 cm thick. At the entrance to the adit, the vein was less than one meter thick. In the adit, limonite-stained quartz is common, and small nodules and veinlets of manganese oxides and botryoidal masses of psilomelane are observed in silicified granite and quartz-vein material (Hewitt, 1959).

At Lead Mountain in the northern part of the district, two abandoned lead mines occur within a vein in Burro Mountains granite. The mines are in a 1.5-3.0 m-thick mineralized shear zone that strikes N.30°-35°E. and dips 58°-65°SE. (Hewitt, 1959). Feldspar in the granite has been intensely kaolinized for distances of up to 7.6m on both sides of the vein; altered granite contains quartz veinlets and minute pyrite cubes (Gillerman, 1964). Samples of the mine dump yielded columnar quartz and galena, both in lenses and as disseminated grains. Material on the dump was coated with chrysocolla, iron, and manganese oxide (Hewitt, 1959).

In Slate Creek Canyon, coarse galena, and minor amounts of sphalerite, bornite, and chalcopyrite are found in breccia in Beartooth Quartzite along a fault striking N.62°E. and dipping 68°NW. Veins of milky to pale amethyst quartz up to 30 cm thick cut the quartzite. Quartz coats breccia blocks and lines cavities. Hewitt (1959) speculated that exploration could yield larger bodies of galena beneath the quartzite.

Copper as malachite, chrysocolla, and tenorite was mined in the early 1900s at the Jennie Mines in North Copper Canyon. Minerals coat the granite footwall and fill narrow fractures near a fault contact between granite and metadiabase that strikes N.60°E. and dips 65°SE (Gillerman, 1964). Manganese at Black Tower Mine 6.4 km south of Cliff occurs in a fracture zone in tuff and rhyolite (Gillerman, 1964).

In the Wild Horse Mesa area, volcanic-epithermal veins contain pyrite, quartz, sericite, gold, uranium, copper, and silver. Fluorite veins predominate (**figure 5-1.6**; **table 5-1.13**). Silification is common (**figure 5-1.7**). Assays from these veins contain as much as 0.07 oz/short ton Au, 1.84 oz/short ton Ag, 480 ppm Cu, 440 ppm Pb, and 1,300 ppm Zn (**table 5-1.14**). Veins follow ring-fractures and radial-fracture faults within the Schoolhouse Mountain caldera. At Purple Heart Mine west of Wild Horse Mesa, fluorite occurs in two slightly radioactive veins striking N.34°-47°W. Fluorite occurs as fracture filling and crustiform masses on granite fragments in a faulted breccia zone (Hewitt, 1959). A sample assayed 0.3 oz/short ton Au and 1,265 ppm Mo (unpublished data, NMBMMR). Uranium occurs in veins along shear zones cutting Precambrian granite and Beartooth Quartzite, as veins and replacement deposits along an

unconformity between Precambrian granite and Beartooth Quartzite, and within fluorite veins cutting Precambrian granite. Other minor radioactive occurrences occur locally in the district. Assays range from 0.009 percent to 0.59 percent U_3O_8. A sample from Prince Albert #1 claim near Wild Horse Mesa assayed 0.09 percent U_3O_8 and trace gold (unpublished data, NMBMMR). There has been no production.

White Signal district

Location, Mining History

White Signal mining district is located about 24 km south of Silver City on U.S. Highway 180. The district is in T. 20 S., R. 14-15 W. and part of R. 16 W. (Gillerman, 1953, 1964). The district encompasses the southeast part of the Burro Mountains and nearby isolated hills and plains to the south and southeast.

Mining began about 1870. Deposit types in White Signal district include Laramide vein, gold placer, and pegmatite deposits. The district has produced fluorspar, uranuim, radium, gold, silver, lead, bismuth, turquoise, garnet, and ocher. From 1880 to 1968, total estimated metal production was 26,000 lbs Cu, 2,500 oz Ag, and 2,200 lbs Pb (**table 5-1.15**). In addition, 1,700 oz Au and 10 lbs of garnet have been produced from placer gold deposits (Johnson, 1972; McLemore, 1994a). No deposit has been explored to greater than 79m depth; workings typically extend to less than 30m depth (Gillerman, 1964).

District Geology

Rocks in the district range in age from Precambrian to Tertiary, and are mostly intrusive rocks. Precambrian Burro Mountains granite predominates (Gillerman, 1964). Pegmatite commonly intrudes the granite in the eastern part of the district.

The oldest rocks are quartz-biotite schist and hornblende schist of the Bullard Peak series of Hewitt (1959), which occur as xenoliths within Burro Mountains granite. Scattered Precambrian diabase dikes are numerous in the southern and western parts of the district and are typically associated with uranium-bearing veins (Gillerman, 1964).

The dikes are as much as 15m wide, can be traced for more than 1.5 km, and widen to form irregular bodies. In many dikes, diabase has been altered to masses of chlorite, iron oxide, epidote, and clay.

The Tyrone quartz monzonite porphyry stock, dated as 56 Ma (Laramide; McDowell, 1971; Hedlund, 1978f, 1985a), occurs in the northwestern part of the district. Quartz monzonite dikes related to the Tyrone stock are common in the northern part of the district. Plugs and dikes of Tertiary rhyolite are also common throughout the district. Many are associated with gold- and uranium-bearing veins, and others cut the veins (Gillerman, 1964;

Hedlund, 1978d,e,f). Rhyolite ranges in age from 42 Ma to 50 Ma (Hedlund, 1985a).

Faults typically are east-northeast- and northwest-trending. Many diabase, rhyolite, and quartz monzonite dikes have been intruded along faults, indicating that the faulting may have taken place in Precambrian time (Gillerman, 1964). The more conspicuous faults (i.e., Blue Jay, Uncle Sam, and Walnut Creek) are up to several km in length. Mineralization and alteration typically occurs where faults, dikes, and fractures intersect.

Mineral Deposits

Laramide vein deposits typically occur in fault breccia, as fissure-fillings along fractures, and in mineralized zones occurring at the intersections of faults, fractures, and dikes. Like the faults, veins trend east-northeast and northwest and appear to be related to 40-50 Ma rhyolite intrusions (Hedlund, 1985a). Because these deposits are localized at fault/dike intersections, they are typically discontinuous and small. Rarely, veins can be traced for more than 150m (Gillerman, 1964). Veins are mineralogically variable; quartz-pyrite-gold, quartz-molybdenite, and more complex vein types are common in the district (Hedlund, 1985a). Veins locally contain gold, native silver, argentite, chalcopyrite, sphalerite, galena, bismuthinite, and uraninite (Gillerman, 1964; Hedlund, 1985a). Assays of as much as 15,300 ppb Au are reported (O'Neill and Thiede, 1982; Hedlund, 1985a). Fluorite veins are apparently younger than polymetallic veins. Silicified rock is common.

Uranium deposits occur as concentrations of secondary uranium phosphate or as disseminations in altered granite and dike rock (Gillerman, 1964). The deposits consist of closely spaced fractures that are filled or coated with uranium phosphate; the coatings are usually less than one mm thick. Autunite and torbernite are the uranium-bearing minerals that are associated with gold, copper, and silver in the oxidized zone. Below the oxidized zone, the primary ore minerals (e.g., native gold, chalcopyrite, argentiferous galena, and specular hematite) are not in sufficient abundance to exploit currently. Bismuth-bearing minerals are reported in some deposits (Gillerman, 1964). Most deposits in the area, except those at the Floyd Collins and Inez Mines, were first mined for base- and precious-metals.

Rare earth-element (REE)-bearing lenses of pegmatite occur in Burro Mountains granite in the western part of the district. These deposits are similar to those found a few km to the south-southwest in Gold Hill mining district (McLemore and others, 1988). Allanite, euxenite, samarskite, and cyrtolite are the rare earth-element-bearing minerals present.

Several intermittent streams in the Burro Mountains have reported placer gold deposits. According to Johnson (1972), the origin of placer gold in Thompson's Canyon and Gold Gulch is not specifically known, but it probably is derived from gold-bearing veins that occur

in the adjacent mountains. In Gold Lake area, placer gold originated from veinlets in a small granite knob, which penetrates through alluvium at Gold Lake. Garnet was also produced from this area (Gillerman, 1964). Johnson (1972) reports that gold placers were worked in Thompson's Canyon and Gold Gulch in 1884 and possibly earlier. The amount of this early production is unknown. Most of the district's placer mining in this century took place in the 1930s.

COOKES RANGE

Northern Cookes Range district

Location, Mining History

Northern Cookes Range mining district lies at the northern end of the Cookes Range in southeastern Grant County (**figure 4-3.2**; Jicha, 1954). Small-scale mining took place in the Northern Cookes Range district , and the area is honeycombed with many small pits, adits, and stopes that have been abandoned (**table 5-1.16**). The largest stope reported by Elston (1957) was 3m high and 7.6m x 4.6m in plan view. Minor silver, lead, and fluorite were been produced from carbonate-hosted lead-zinc, fluorite vein, and Rio Grande Rift barite-fluorite-galena deposit types (see Sutphin, this volume).

Fluorite mining at White Eagle Mine probably began prior to 1918 (Elston, 1957). The mine was operated by four lessees from 1933 to 1945; production was estimated at 17,000 short tons of ore (Rothrock and others 1946). USBM conducted limited diamond drilling in April-June 1945, and intersected veins assaying as much as 79.6 percent CaF_2 (Morris, 1974a). Ozark-Mahoning Co. of Tulsa, OK, leased the property in 1950, shipping about 12,300 short tons of ore averaging 61.7 percent CaF_2 in 1953-1954. Southwest Fluorspar Co. of Deming leased the property from 1969 to 1972, and shipped about 5,500 short tons of ore. Total ore production from White Eagle Mine was about 62,300 short tons, and Linda Vista and Wagon Tire Mines totalled about 1,500 short tons (Morris, 1974a).

District Geology

Cookes Range is a series of northwest-trending hills with low to moderate relief, bounded on the northeast by the N.20°W.-striking Sarten Fault and on the southwest by an inferred fault with similar trend (Morris, 1974a). In the Northern Cookes Range district, the oldest rocks exposed are Precambrian, consisting mainly of quartz-microcline-biotite granite and granite gneiss (Elston, 1957). The rocks are cut by quartz-microcline pegmatite and Tertiary (?) rhyolite dikes (Morris, 1974a). Granite gneiss extends northward outside of the district, where it grades into hornblende-chlorite schist. Precambrian rocks are highly fractured and altered, particularly near fluorite mineralization; biotite is chloritized and orthoclase is

sericitized.

Cookes Range Fault, which is the eastern range-front fault, nearly bisects the district, and is inferred to bifurcate northward beneath Tertiary and Quaternary alluvium (Elston, 1957). A western range-front fault is inferred to lie beneath Quaternary alluvium. The district comprises a fault block of Paleozoic rocks. East of the fault block, Santa Fe Group and Quaternary alluvium predominate; west of the fault block, Precambrian rocks crop out or are overlain by porphyritic White Eagle Rhyolite. White Eagle rhyolite forms flows, sills, and dikes and is confined to the northern end of the Cookes Range.

Fusselman Dolomite, Percha Shale, and Lake Valley Limestone comprise a small part of the Northern Cookes Range fault block (Morris, 1974a). These rocks are highly shattered. Mineralization and silicification are confined to the upper Fusselman Dolomite, where rising mineralizing solutions may have confronted the impermeable Percha Shale.

Mineral Deposits

Carbonate-hosted lead-zinc, fluorite vein, and Rio Grande Rift barite-fluorite-galena deposit types are present in the district (**table 5-1.16**). Fluorite occurs in three modes: (1), steeply dipping veins of replaced andesite cutting Precambrian rocks; (2), fracture fillings in narrow, siliceous veins in monzonite and andesite flows (Morris, 1974b); and (3), replacement blankets (mantos) in carbonate rocks. Mineralization is probably mid-Tertiary in age (Williams, 1974a). At the lower levels of White Eagle Mine, the vein is offset about 11m by post-mineralization faulting (Williams, 1966). Replacement fluorite occurs in mantos in gently dipping andesite at the Linda Vista Mine (Morris, 1974a). Silicification, argillization, chloritization, and sericitization are alteration types present in the Northern Cookes Range district and were important in fluorite deposition (Morris, 1974a). At Linda Vista Mine, ore occurs as small, irregular veins in volcanic fault breccia of Tertiary age. At Defense prospect, 0.8 km southeast of Linda Vista Mine, siliceous fluorite occurs in stringers and pockets in Precambrian granite (Rothrock and others, 1946)

Silver as cerargyrite was mined and sulfides with minor galena were present (Morris, 1974b). Cerussite, smithsonite, hemimorphite, and iron and manganese oxides and hydroxides were identified in old workings (Elston, 1957).

GOLD HILL

Gold Hill district

Location, Mining History

Gold Hill mining district (Camp Bobcat) is in the western Burro Mountains, Grant and Hidalgo Counties, about 20 km northeast of Lordsburg. It has a history of intermittent mining

similar to other mining districts.

Gold was discovered in 1884 at Gold Chief claim and a stamp mill was erected in 1886 (Gillerman, 1964). By the 1890s, many small mines were active. The mining town of Gold Hill had an estimated population of 500 people at its peak. By 1900, shallow, free-milling oxidized ore was exhausted, and the area was in steep decline. Shortly after 1900, Frank Cline acquired the rights to several mines in the district, mining them until his death in 1940. From 1920 to 1926, several hundred short tons of high-grade silver ore were mined. During the 1920s, Co-op Mine produced greater than $100,000 in silver (Richter and Lawrence, 1983). From 1932 to 1940, a revival in gold mining resulted in gold production (worth $18,934). Mining was limited to the oxidized zone above the water table.

Prospecting and development of the larger pegmatites occurred between 1952 and 1955, but the amount and concentration of the rare-earth minerals was so low that mining soon ceased. The same deposits were mined as a source of mica, but grade and tonnage were insufficient, and the mines were abandoned. In 1954, Bluebird gold mine was rehabilitated during exploration for tungsten. From 1956 to 1960, development work was undertaken at the Never Fail Mine (Richter and Lawrence, 1983).

Total production from the district from 1911 to 1941 amounts to 6,845 lbs Cu, 1,620 oz Au, and some silver and lead (**table 5-1.17**). Prior to 1944, 3,000 short tons of ore averaging 50 percent CaF_2 were produced at the Bluebird Mine; from 1944 to 1949, the mine was worked intermittently with minor production. About 500 short tons of beryl were produced from Grandview Mine (Griffitts, 1965).

District Geology

The district is composed mainly of Proterozoic Burro Mountains granite (Hedlund, 1978f) surrounded by Quaternary deposits on the west and Tertiary volcanic rocks on the east (**figure 4-1.2**; Beard and Brookins, 1988). The oldest rocks in the district form the Bullard Peak series of Hewitt (1959) and consist of migmatite, quartz-biotite gneiss, hornblende gneiss, and amphibolite. This intrusive episode was followed by pervasive retrograde alteration that resulted in chloritization, sericitization, and epidotization of mafic rocks, intrusion of Precambrian diabase dikes and plugs, basaltic, rhyolitic, and felsic dikes, and fracturing of rocks. Rhyolite dikes locally contain disseminated and oxidized pyrite.

Gold Hill mining district occurs at the junction of structural elements, indicated by diabase dikes trending N.30°W., pegmatites, and the N.70°E.-trending Co-Op-McWhorter Fault (Gillerman, 1964; Hedlund, 1978f; Beard, 1987). Co-Op Mine is located where the fault intersects pegmatite.

Mineral Deposits

The district contains Laramide vein, fluorite vein, gold placer, and pegmatite deposit types (**table 5-1.18**). Veins are mostly gold-bearing quartz veins, but silver and base metals are major constituents locally. Fluorite veins occur on the east side of Gold Hill. In the northern part of the area, pegmatite contains rare-earth minerals. Geochemical anomalies in stream-sediment samples include Ag, Be, Co, Cu, Mn, Mo, Pb, and Zn (Hassemer and Marsh, unpublished data, 1995). The Gold Hill area coincides with an aeroradiometric Th high (see Pitkin, this volume).

Two types of Laramide vein deposits are present --gold-bearing quartz veins and silver-base-metal veins. Gold-bearing quartz veins are numerous, and are the sites of nearly all mining in the district. Gold placers occur in Holocene gravels in Gold Hill Canyon and result from the weathering of gold-bearing quartz veins.

Late Cretaceous or early Tertiary gold-bearing quartz-vein mineralization formed as hydrothermal fracture fillings in Precambrian granite or at the contact between hornblende gneiss and granite (Gillerman, 1964). Veins have banded, drusy textures indicative of a shallow to moderate depth of formation. They are irregular and variable, ranging from a few cm to several meters wide and as much as 100m long (Gillerman, 1964; Beard, 1987; unpublished data, NMBMMR). Almost all gold-bearing veins are localized within mafic rock, commonly occurring at the contact with surrounding basic dikes, biotite schist, amphibolite, granite, or granite gneiss. Little is known of the mined ore. Galena, sphalerite, possible ruby silver, limonite, and pyrite are present on mine dumps today. Minor scheelite and wolframite occur at Bluebird Mine (north side, Engineer Canyon; secs. 6, 7; T. 22 S., R. 16 W. (Hedlund, 1978f). At Reservation Mine where andesite is in contact with the vein, host rock is mostly hornblende and mica schist with localized garnet gneiss. At Bluebird Mine, the vein is 1.2-1.8m wide. In many stopes, the ore contained 1-3 oz/short ton Au, and similar amounts of silver occurred locally in veins.

Silver base-metal veins occur in the southern and eastern parts of the district. The deposits contain primary argentiferous galena, pyrite, and sphalerite, with calcite and quartz gangue (Gillerman, 1964). Cerussite, native silver, and limonite are present in oxidized parts of the vein. At Co-Op Mine, the highest silver values are associated with galena and pyrite in the sulfide zone, and with cerussite and limonite in the oxidized zone. Negligible amounts of gold are present.

Gold grade of the ore was variable, but generally low. Average values of the ore ranged from $15 to $40 per short ton; some ore was valued as high as $125 per short ton

(Lindgren and others, 1910). Values cited by Gillerman (1964) for production in the 1930s, when gold was worth $35 oz, indicate that ore shipments averaged $15.41 in Grant County and $25.41 per short ton in Hidalgo County.

Rare-earth element pegmatite in the district occurs in Burro Mountains granite (McLemore and others, 1988). Deposits range from pods a few cm across to lens-shaped bodies several tens of meters in length and width (**figure 5-1.8**). Two veins 0.6m wide and 14m long were located in this study. Minerals in the pegmatite bodies include quartz, microcline, albite, muscovite, biotite, magnetite, garnet, fluorite, and rare-earth-bearing minerals, such as allanite, euxenite, samarskite, and cyrtolite (**figure 5-1.9**). Thorium, niobium, tantalum, and beryllium are present. One vein contains 0.05-0.72 weight percent thorium. Pegmatites are zoned, with coarse quartz and small segregations of microcline at the core (Gillerman, 1964). Surrounding the core is a quartz-perthite zone containing muscovite and biotite. This zone is surrounded by a quartz-albite-muscovite or quartz-albite-microcline zone. The outermost zone is composed of quartz-microcline. At South pegmatite, massive green fluorite occurs in the quartz-albite-muscovite zone.

At Bluebird deposit on the northeast side of Gold Hill (NE $^1/_4$, sec. 22, and NW $^1/_4$, sec. 23; T. 21 S., R. 16 W.), fluorite occurs in stringers and veins 0.3-0.6m wide within breccia and in a sheeted zone 0.6-2.4m wide within Precambrian granite. Fluorite in 15m x 914m lenses occurs in a zone that strikes N.85°W.-N.75°E. and dips 70°-80°N. Coarsely crystalline masses of white, green, violet, and purple fluorite are associated with quartz and silicified granite wallrock. Limonite, calcite, pyrite and possibly gold are present (Gillerman, 1964).

MIMBRES MOUNTAINS

Carpenter District

Location, Mining History

Carpenter (Swartz) mining district, on the rugged western slope of the Mimbres Mountains, is about 10 km southwest of Kingston and 17 km east of Mimbres. The district is the site of moderate base-metal production from low-grade deposits (**table 1-3**).

In the 1880s, mineralization was discovered at the Royal John property (Soulé, 1950). The first recorded mining venture at the Royal John Mine in 1906-07 was unsuccessful (Harley, 1934). The district has been the site of moderate base-metal production from low-grade deposits (**table 5-1.19**). The mine and mill were operated from 1928 to 1930 by ASARCO and Albert Owen of the Black Range Mining Company. Production until 1934 was estimated to be 15,000 short tons ore (Harley, 1934). From 1943 to 1948, USGS and the

USBM undertook diamond drilling to determine the extent of mineralization. USBM proposed additional development at Royal John Mine to increase reserves of low-grade lead-zinc ore.

At least five mines in the Grant County portion of the district have produced zinc, lead, copper, silver, and traces of gold. Royal John Mine is the largest producer, with sporadic production from 1916 until 1969. Other mines in the district operated for shorter periods -- mainly the years during and shortly after World War II. Total production from 1891 to 1969 was about 12.5 million lbs Zn, 6 million lbs Pb, 310,000 lbs Cu, 60,000-180,000 oz Ag, and 300 oz Au. Average ore grade was 7.95 percent Zn, 3.9 percent Pb, 1.1 oz/short ton Ag, and 0.12 percent Cu.

District Geology

The district lies within a horst of Paleozoic sedimentary rock between two north-trending faults --the Mimbres fault on the west and the Owens fault on the east (Kinney, 1944) (**figure 5-1.10**). West of Grandview Mine, Paleozoic sedimentary rocks are intruded by granite porphyry (Lindgren and others, 1910). Elsewhere, andesite and rhyolite flows overlie sedimentary units. A gently west-dipping homocline in the central and southern parts of the district, and a north-trending, doubly-plunging anticline with a core of Precambrian granite are exposed near Grandview Mine (Hedlund, 1985b). Discovery and Sunshine faults cut the horst in the vicinity of Royal John Mine and have economic importance. Mineral deposit types in the district in Paleozoic carbonate rocks are base-metal skarn and carbonate-hosted lead-zinc (see Sutphin, this volume).

Mineral Deposits

Mineral deposits within the Carpenter mining district and USBM investigations have been studied and described (Lindgren and others, 1910; Harley, 1934; Hedlund, 1977b, 1985b; Ericksen and others, 1970; Hill, 1946; and Soulé, 1950)(**table 5-1.20**; **table 5-1.21**). Ore deposits are small, low-grade skarn and replacement deposits in Montoya Group dolomite, and are related to emplacement of rhyolitic plutons of Oligocene age (35 Ma.; Hedlund, 1977b). Most veins are fault controlled, and skarns with replacement deposits are well developed in the upper cherty beds of El Paso Limestone (Hedlund, 1985b).

At Royal John Mine, replacement ore bodies occur within a horst bounded by the N.10°-25°W.-trending Owens and Grandview faults. Deposits are at the top of the cherty thin-bedded member within the Montoya Group, are as much as 4m thick, and extend as far as 91m west of Discovery fault (Soulé, 1950; Hedlund, 1985b). Mineralization may extend locally along fault zones into the cherty, thin-bedded Montoya Group rocks and underlying massive limestone. Galena and sphalerite are principal ore minerals associated with quartz, calcite, chalcopyrite,

and pyrite. Abundant skarn minerals, such as garnet, epidote, chlorite, and magnetite, occur locally in altered limestone. Helvite, a beryllium mineral, was first discovered at Grandview Mine (Weissenborn, 1948). At Royal John Mine, sphalerite is the main economic mineral, with lesser galena. No calc-silicate skarn minerals are noted at Royal John Mine, but the rocks are silicified (Soulé, 1950).

At Mineral Mountain Mine, carbonate-hosted replacement deposits extend for about 9m along marmoritized and cherty beds of Lake Valley Limestone. Mineralized faults, strike N.30°W. and N.30°E.; dike margins contain minor galena, sphalerite, and pyrite (Hedlund, 1985b). At Columbia Mine, sulfides closely associated with tactite in El Paso Limestone are cut by a 32-m-thick rhyolite dike (Hedlund, 1977a).

LITTLE HATCHET MOUNTAINS

Little Hatchet Mountains include the Eureka district (see also Sylvanite district).

Eureka district

Location, Mining History

Eureka mining district occurs in the northern part of the Little Hatchet Mountains in Grant County. Mining activities in the Little Hatchet Mountains began in 1871. However, stone tools found in old turquoise pits are evidence of prehistoric activity. American, Hornet, and King claims were located in 1877-1878 when the Sylvanite district was prospected. Eureka and Sylvanite mining districts were originally subdistricts of the Hachita district.

Earliest mining was at Hornet Mine. However, Apaches were hostile to mining and prospecting and by late 1878, the U.S. Army discovered that only 20 people resided in the district. Protection afforded by the Army allowed the miners to return, and in 1881, ore shipments from the American Mine were recorded. In the early 1880s, smelters were built at both the American and Hornet Mines, but neither smelter operated for long. From 1885 to 1902, owing to low prices for silver, mining activities waned. In 1902, the railroad connected the smelter towns of Douglas, Ariz., and El Paso, Tex., and stimulated production in the district. Total value of ore produced up until 1906 was no more than $500,000 (Lindgren and others, 1910). Total estimated production from Laramide vein deposits included 2.9 million lbs Pb, 1.7 million lbs Zn, 500,000 lbs Cu, 5,000 oz Au, and 450,000 oz Ag (**table 5-1.22**).

District Geology

In the district, Tertiary stocks, dikes, and sills intrude Cretaceous sedimentary and Tertiary volcanic rocks. Cretaceous sedimentary rocks consist of thin bedded limestone, dolomite, and shale. Between Howells Ridge and Old Hachita, Hidalgo Volcanics consist of

altered andesite and andesite breccia and detrital sedimentary rocks containing andesite clasts. Hornblende andesite near the base of the section is dated as 71Ma ($^{40}Ar/^{39}Ar$, hornblende; Lawton and others, 1993).

South and west of Old Hachita, the Hidalgo Volcanics are intruded by quartz monzonite and diorite; quartz monzonite and monzonite of the Sylvanite stock crop out in the Sylvanite and Eureka districts (Zeller, 1970). In the Little Hatchet Mountains, Laramide stocks, dikes, and sills intrude Cretaceous sedimentary rocks; mineralized areas are associated with the intrusive rocks.

Mineral Deposits

Laramide vein deposits in limestone and monzonite, Laramide skarn and replacement deposits in metamorphosed limestone along the edge of the intrusive rocks, turquoise deposits, and disseminated quartz-specularite deposits (**table 5-1.23**) comprise the Eureka district. Seven types of deposits, based on mineralogy, are: (1), disseminated pyrite in Tertiary intrusive rocks; (2), quartz-specularite deposits (sec. 2, 11; T. 28 S., R. 16 W.); (3), lead-zinc skarn and replacement deposits (Hornet); (4), arsenopyrite-lead-zinc vein deposits (American, Miss Pickel); (5), manganosiderite-galena veins; (6), manganosiderite- tetrahedrite-galena vein (King 400, Silver King, Howard); and (7), quartz-pyrite-chalcopyrite deposits (Copper King, Stiles)(Lasky, 1947).

Ore deposits at American Mine occur along a vein that strikes N.50°E. and dips 58°-75°NW; the deposits are in limestone that has been metamorphosed to marble and garnet near the contact with monzonite (Lasky, 1947). The vein can be traced for about 305m before plunging beneath arroyo gravels. In the mine, the vein is 0.6-6.0m wide. Mineralized vein material contains galena, sphalerite, pyrite, arsenopyrite, and trace chalcopyrite. Gangue material includes manganosiderite, calcite, and sericite.

Hornet Mine, one of the earliest mining locations in the Little Hatchet Mountains, is the site of the greatest mining activity in the mountain range. Host rocks at the mine include unnamed limestone, Hidalgo Volcanics, and an irregular diorite sill intruding the contact between the limestone and volcanic rocks. Ore at the mine consisted of three types: (1), lead-carbonate ore stained by manganese oxides, averaging 25 oz/short ton Ag; (2), galena ore rich in silver; and (3), zinc-carbonate ore rich in silver. Grade of material shipped between 1905 and 1927 was about 22 oz/short ton Ag, 3.5 percent Zn, less than one percent Pb, and 0.05 percent Cu. Most gangue is coarse-grained calcite. Pyrite occurs in unoxidized rock.

Turquoise deposits were rediscovered about 1885 and were worked intermittently for at least 25 yrs. Blue and green turquoise in veins up to 2m wide was mined from altered

trachyte, andesite, and ash-flow tuff (**figure 5-1.11A**, **figure 5-1.11B**); most veins are smaller (**figure 5-1.12A; figure 5-1.12B**; **figure 5-1.13**)(Sterrett, 1911). Impurities include jarosite, sericite, iron oxides, pyrite, and clay (Lasky, 1947). Total production is unknown.

Zones of disseminated pyrite are present in altered monzonite. Unaltered, pre-ore lamprophyre dikes cut the altered monzonite in the Sylvanite district to the south, suggesting that alteration is older than mineralization (Lasky, 1947).

A zone of disseminated quartz-specularite occurs in diorite and andesite breccia (sec. 2 and 11, T. 28 S., R. 16 W.)(Lasky, 1947) that has been locally sericitized and replaced. Iron was produced for use in the Hornet and American smelters.

MOGOLLON MOUNTAINS

Wilcox district

Location, Mining History

One-third of the Wilcox (Seventy-four) mining district is in northwest Grant County; the remainder is in Catron County. About 1,500 mining claims have been staked since discovery of the district in 1879. It has been the site of active mining and exploration, but little production (Ratté and others, 1979). Most mines are in Catron County, but numerous claims, prospect pits, shafts, and adits are present in Grant County (**table 5-1.24**; **figure 5-1.14**).

This part of New Mexico was inaccessible in the late 1890s and early 1900s; early production was transported to the mill by pack train (Rothrock and others, 1946). At least 10,603 short tons fluorite, 17 oz Ag, less than 100 oz gold, some copper, and 5 short tons of tellurium ore have been produced from this district (**table 1-3**, **table 1-5**; Ratté and others, 1979), but it is not known what part of this production came from Grant County.

District Geology

Rocks of the Mogollon-Datil volcanic field overlie several hundred meters of Mesozoic and Paleozoic sedimentary rocks. Mesozoic and Paleozoic rocks are underlain by Precambrian basement, except where they are intruded by the batholithic rocks that are suggested to underlie much of the volcanic field (Elston and others, 1976; Ratté and others, 1979). Volcanic rocks in the district are mostly middle to late Tertiary in age. They are overlain locally by younger conglomeratic units or are covered by unconsolidated sand and gravel deposits (Ratté and others, 1979).

In Grant County, the oldest volcanic formation is the Cooney Tuff. Pre-Bursum caldera rocks (Miocene and Oligocene andesitic and basaltic lava flows and flow breccias) overlie these rocks (Elston, 1994). Younger rhyolite flows and domes of Miocene and

Oligocene ages overlie the pre-caldera rocks in the southern part of the district (Ratté and others, 1979). The rhyolite is mainly flow-banded and spherulitic to porphyritic rhyolite, and is associated with pyroclastic and volcaniclastic rocks. The thick volcanic blanket may cover unidentified mineral deposits that may be present deeper in the volcanic sequence or in underlying rock.

Mineral Deposits

Wilcox mining district lies along northwest-trending faults that are related to the Bursum caldera (Elston, 1994) at the western edge of the Mogollon-Datil volcanic field. Deposit types between Haystack and Seventyfour Mountains include volcanic-epithermal fluorite (±Au) and quartz vein in mineralized faults within in volcanic rocks. Veins are scattered in the Wilcox district (Ratté and others, 1979). Epithermal manganese and barite deposits also occur. Brecciated and banded textures are common. Assays from the district range as high as 1.3 oz/short ton Au, 16.16 oz/short ton Ag, 7.05 percent Cu, and 9.01 percent Zn (Ratté and others, 1979). In the Little Dry, Pine, and Sacaton Creek areas, samples assayed as much as 3,500 ppm Te (Ratté and others, 1979). Mineralization in most of the district is controlled by north- and northwest-trending fracture zones, rhyolitic intrusions in the ring-fracture zone of Bursum caldera, and northeast-trending fractures in the resurgent dome of the Bursum caldera.

Local acid-sulfate alteration with alunite has been dated as 31-33 m.y. (Marvin and others, 1987). Silicic, argillic, and acid-sulfate alteration suggest the potential for deposits at depth. Datil volcanic field is near the intersections of major regional tectonic trends, and near significant precious- and base-metal, iron, and manganese deposits (Ratté and others, 1979). Regional alteration consists of kaolinite, chlorite, and silica alteration. Little subsurface exploration has taken place.

In Grant County, most deposits are small fissure-filling fluorite vein deposits. At Margie Ann Mine, a 46-m long adit was driven along a northwest-trending fault. A high-grade copper-bearing quartz vein is exposed along the east wall of the adit. A small lens was assayed and contained 0.04 oz/short ton Au, 3.66 oz/short ton Ag, 7.05 percent Cu, and minor Pb, Bi, Mo, and W (Ratté and others, 1979).

At Seventyfour Mountain prospect, narrow fluorite veins are in Cooney Tuff adjacent to the footwall of a 9-m-wide rhyolite dike that strikes N.12°W. and dips 84°W. Veins occur in a cross-fault zone, which offsets the dike (Williams,1966). The vein adjacent to the dike consists of 15 cm of high-grade fluorspar and 15 cm of brecciated material with fluorspar. Total traceable length of the vein is about 30 m. One sample contained 56.77 percent fluorite (Ratté and others, 1979). At Rainbow prospect, three narrow fissure veins in rhyolite and andesite within 30m of each other

occur. They contain fluorspar in coarsely crystalline, fissure-filling material. The veins strike S.35°W.-S.10°E. and dip 80°W. Samples from two veins contain 55.0 percent and 78.9 percent CaF_2 (Williams, 1966).

At Gold Spar Mine, a breccia zone 0.3-3.0m wide contains fluorite, calcite, and quartz fracture filling deposits. High-grade veins are 30-152cm wide, and are exposed for as much as 150m (Gillerman, 1964). Ore sold to the mill at Silver City assayed 74.0 percent CaF_2 (Williams, 1966).

PINOS ALTOS RANGE/ SILVER CITY RANGE

Piños Altos and Silver City ranges include the Bayard, Chloride Flat, Copper Flat, Fierro Hanover, Fleming, Georgetown, Gila Fluorspar, Lone Mountain, Piños Altos, and Santa Rita districts and comprise the largest mining area in New Mexico.

Bayard district

Location, Mining History

Bayard (Central) mining district, between Silver City and Santa Rita, has been included with deposits from the Santa Rita and Fierro-Hanover districts (Anderson, 1957). Lasky (1936b) notes that Central mining district includes claims near the town of Central and the Hanover, Fierro, and Santa Rita subdistricts. In this study, the Bayard district is restricted to the immediate vicinity of the town of Bayard (**table 5-1.25**) and the Central district is not used.

Bayard district was discovered in 1858 and total production is estimated to be 110 million lbs Cu, 24,000 oz Au, 7.5 million oz Ag, 225 million lbs Pb, and 809 million lbs Zn (**table 1-3**). Laramide vein and placer gold deposits (see Sutphin, this volume) are found in the district. Manganese has been produced from mines on the Manhattan and Pleasant View claims that were patented for lead and zinc in 1903. Each produced several carloads of high-grade lead-zinc ore (Farnham, 1961).

San Jose claim (part of the Ground Hog mining operation) is one of the oldest mining claims in the area (Lasky, 1936b) (**figure 5-1.15**). It was mined for copper, gold, and silver prior to 1869. Ground Hog and Lucky Bill claims were located in 1900 where the vein at the junction of Lucky Bill Canyon and Bayard Canyon is exposed.

District Geology

Owing to the extensive mining that has taken place over the past 100 yrs, much is known about the Bayard district and surrounding rocks (Lasky, 1936b). Jones and others (1967) provide the most recent discussion of the geology of the Santa Rita quadrangle, which includes the district.

Exposed rocks in the area range in age from Pennsylvanian to Recent. Rocks of Pennsylvanian and Cretaceous age are broken by faults, locally domed and folded by forceful

injection of Late Cretaceous-Tertiary magma, and intruded by of northeast-trending dike swarms (Jones and others, 1967). To the south, flat-lying volcanic rocks of Miocene(?) age overlie the older sedimentary rocks and form dissected plateaus. Oswaldo Formation (cherty limestone, thin beds of shale, and lenses of sandstone) and Syrena Formation (limy shale and argillaceous limestone) are exposed; Triassic, Jurassic, and Early Cretaceous strata are absent. Late Cretaceous sedimentary rocks include Beartooth Quartzite and Colorado Formation (lower black shale member and upper sandstone member).

At least 25 intrusive and extrusive rock types occur in the Santa Rita quadrangle (Jones and others, 1967), including sills, laccoliths, stocks, dikes, and plugs of Late Cretaceous(?) and Early Tertiary age, flows, dikes, tuffs, and plugs of the Rubio Peak Formation, Sugarlump Tuff, and Kneeling Nun Tuff. The latter of these two units make up the bulk of San Jose Mountain in the southern part of the area. Quaternary deposits overlie these sequences locally.

Bayard area is near the eastern limb of the Pinos Altos-Central syncline. Four periods of normal faulting, downthrown to the southeast, have been recognized in the Bayard area: (1) faulting subsequent to the intrusion of the sills, along which granodiorite porphyry dikes were later injected, (2) faults generated after injection of the dikes, (3) faults generated after expulsion of the volcanic rocks, (4) and faulting that occurred near the end of the explosive stage of volcanic activity (Bayard and Ground Hog faults)(Lasky, 1936b).

Mineral Deposits

Most Laramide vein deposits in the Bayard district are precious- and base-metal fissure fillings and replacement bodies in faults and fractures that have been enriched both by supergene and hypogene processes. At Ground Hog Mine, granodiorite dikes intrude quartz diorite porphyry of the Fort Bayard laccolith, with in-faulted masses of Colorado Formation shale in a 200 ft-wide fracture zone. Ore occurs within fractures and fracture zones in the granodiorite dikes and their wall rocks (Spencer and Paige, 1935). Hypogene ore minerals include chalcopyrite, galena, and sphalerite. Supergene ore minerals include chalcocite pseudomorphs after galena, cerrusite, wulfenite, and goslarite. Vanadium as cuprodescloizite occurs at the Ground Hog Mine (Lasky, 1930, 1936b).

At Ivanhoe and Ninety Mines (both under mine waste dumps near the Chino Mines concentrator), ore is in fissure filling and replacement deposits along contacts between a granodiorite porphyry dike, shaly limestone, and a quartz diorite sill of the Colorado Formation. Chalcopyrite is irregularly distributed, and narrow bands of fine-grained galena that parallel the fault are associated with sphalerite. Cerussite and pyritic chalcocite are abundant supergene minerals (Lindgren and others, 1910).

Manganese mineralization at the Manhattan and Pleasant view claims consists of pyrolusite, wad, and some psilomelane veins that are associated with lead-carbonate and lead-zinc sulfides within a fissure zone in quartz diorite porphyry. Assays are shown in **table 5-1.26**. The fissure zone ranges from 5m to 10m wide, strikes N.30°E., and dips steeply SE. Manganese minerals occur in narrow stringers, in bands 3m wide, and as irregular veinlets and stringers more than 1.5m long (Farnham, 1961).

Experienced gold panners found that the gold content of the sands was directly related to vein occurrences (Lasky, 1936b). Thus, placers follow pre-volcanic drainages; even the smallest arroyos have derived placer gold from veins in the area (Lasky, 1936b). The most productive placer grounds are north of San Jose Mountain and east of Central. Gold dust with a fineness of 0.705 is typical, but nuggets as large as a small lima bean have been won. Less than 1,000 oz of gold were produced from the placers (Johnson, 1972; McLemore, 1994b).

Chloride Flat district

Location, Mining History

Chloride Flat mining district [Silver City or Boston Hill district of File and Northrop (1966)] is located 2.5 km west of Silver City. Silver was first discovered in 1871. Silver-producing years were 1873-1893; silver production took place as late as 1937 (Lindgren and others, 1910; Richter and Lawrence, 1983). Although the district is better known for its silver ore, 2.7 million short tons of manganiferous-iron ore containing 12 percent Mn and 30-40 percent Fe were produced through 1962 (Harrer, 1965), most from the Boston Hill Mines. Ore was valued for its fluxing qualities, which permitted mining of low-grade material (Hernon, 1949). Total production from the carbonate hosted silver-manganese deposit type (see Sutphin, this volume) is estimated to be 20,000 lbs Cu, 200 oz Au, 4 million oz Ag, and 500,000 lbs Pb (**table 5-1.27**).

Early mining history of Chloride Flat mining district and the Silver City area was influenced by the 1871 discovery and subsequent development of rich silver deposits near the Chloride Flat Mines (Entwistle, 1944). In this area, supergene silver ore accounted for the bulk of production, with a small tonnage of manganiferous iron. Similarity of ores in the district to those of the neighboring silver districts resulted in considerable prospecting for silver, but little new discovery.

District Geology

Chloride Flat district is comprised of a sequence of Paleozoic sedimentary rocks (mostly limestone and shale) that rest on Precambrian granite (Lindgren and others, 1910). The rocks strike N.35°W. and dip 25°NE and are cut by dikes and sills of granodiorite porphyry or quartz monzonite porphyry (Lindgren and others, 1910). Porphyrytic dikes and sills commonly cut

Percha Shale or Colorado Formation shales. Oxidized silver and manganiferous-iron replacement and vein mineralization is related to the porphyry intrusions, with the ore bodies having formed near the intrusives at the Fusselman Dolomite-Percha Shale contact.

Lower Paleozoic sedimentary rocks and Cretaceous shales that are separated by a fault crop out in the vicinity of Boston Hill Mines. A large elliptical plug, slightly to intensely hydrothermally altered, of quartz monzonite porphyry and associated dikes invade the sedimentary rocks in the eastern Boston Hill Mine area.

Mineral Deposits

Chloride Flat mineral deposits are oxidized silver veins and replacements of the carbonate-hosted silver-manganese deposit type; they are generally associated with lead and manganese minerals (**table 5-1.28**). Deposits form as irregular supergene-enriched bodies localized along a 914-m-long zone of fractures, joints, and beds in Fusselman Dolomite at the contact with Percha Shale. Most faults are downthrown to the east. As with several other districts in the study area, the location of ore bodies at the shale contact is attributed to entrapment of hydrothermal solutions in the upper part of the Fusselman Dolomite and below impervious Percha Shale beds. Within the ore bodies, limestone is altered but shows no evidence of calc-silicate skarn development (Richter and Lawrence, 1983). Hernon (1949) notes that the ore bodies lie between walls of dolomite that are altered to calcite.

Lake Valley Limestone underwent two periods of recrystallization --one at 335°C-380°C during Late Cretaceous-Early Tertiary intrusions, and a later one at 165°C-260°C (Young, 1982). Limestone is replaced by quartz, galena, argentite, hematite, pyrolusite, magnetite, limonite, and oxidized compounds of lead and silver (Lindgren and others, 1910). Cerargyrite, native silver, and argentite are the principal silver minerals; minor embolite, pearcite, and argentiferous galena, bromyrite (silver bromide), and silver iodide are reported (Hernon, 1949; Lindgren and others, 1910). Much of the silver was derived from primary argentite (Entwistle, 1944). Lead values are low.

Principal occurrences of manganiferous iron ore at Chloride Flat are within a steeply dipping, north-trending fracture zone that cuts Fusselman Dolomite (Kelley, 1949; Farnham, 1961). Ore bodies 15-76m long and 9-18m wide are exposed in open cuts for 610m along strike. Ore is a mixture of hematite and pyrolusite, with some magnetite and limonite (Entwistle, 1944; Kelley, 1949). Mestitite (a brown to grayish-brown Fe-Mg carbonate mineral), specularite, magnetite, and some sulfides were trapped beneath Percha Shale. These were oxidized and concentrated to manganiferous iron ores by supergene processes above the water table. At Chloride Flat, the manganiferous-iron deposits are not as large as those at Boston Hill (Kelley,

1949) and are less important as sources of manganiferous-iron, owing to their high silver content.

At Boston Hill, ore mined from 1937 to 1944 assayed 12-13 percent Mn and 35-41 percent Fe. Manganiferous iron ore at Boston Hill is an intimate mixture of hematite and pyrolusite with lesser magnetite and limonite (Farnham, 1961). At both the Chloride Flat and Boston Hill deposits, gangue consists of small amounts of calcite, quartz, and barite. At both deposits, mesitite is the primary hypogene mineral. Oxidation of mesitite by meteoric waters is responsible for the mineralization (Entwistle, 1944). However, only the deepest mine workings have penetrated the mesitite bodies.

In the Boston Hill area, ore is found in irregular bodies localized along steeply dipping fault and fracture zones. The ore replaces El Paso Limestone and Montoya Group dolomite that is overlain by Percha Shale in the eastern half of the area (Farnham, 1961). The northern extent of mining is bounded by the Boston Hill fault, which strikes N.60°E. and dips 70°NW to vertical.

Copper Flat district

Location, Mining History

Copper Flat mining district, prospected for copper in the late 1800s when most shafts were sunk, is located in the Piños Altos Range near Bayard about 3 km west-southwest of Hanover (Mullen and Storms, 1948). A small amount of iron was produced from surface deposits between 1931 and 1937. In 1940, an extensive exploration program began, which led to base- and precious-metal production between 1942 and 1947. From 1931 to 1937, 10,000 short tons of iron ore were mined from surface exposures. Between 1942 and 1947, ore containing about 27,000 short tons Zn was mined from underground workings, along with some Cu, Pb, Au, and Ag (Richter and Lawrence, 1983). Total production from the lead-zinc, copper, and iron skarns is not known.

Iron production from the magnetite mine was intermittent; data is available only for 1931 and 1937. Iron ore had an average composition of 57.6 percent Fe, 13.3 percent SiO_2, 0.5 percent Zn, and 0.047 percent P (Kelley, 1949). Reserves were estimated to be several tens of thousands of short tons of material containing 50-55 percent Fe (Kelley, 1949).

District Geology

The district is centered around the two small, closely spaced exposures of hypabyssal igneous plugs of intermediate composition (Copper Flat stock). Spencer and Paige (1935) indicate that the two intrusive plugs intrude the Lake Valley Limestone and Oswaldo Formation (Kelley, 1949) and connect at shallow depth.

Copper Flat granodiorite stock, about 610m long and 365m wide, lies on the Fort Bayard anticlinal axis (Jones and others, 1967). Near the contact of the stock and the Oswaldo Formation, disturbed rocks locally dip toward the intrusive (Kelley, 1949). The contact aureole around the stock

is 30-213m wide, consisting of an inner zone of garnet, magnetite, and sulfides and an outer zone of marble (Spencer and Paige, 1935).

The larger plug is 274m x 548m and is composed of fine-grained granodiorite porphyry with a dike-like intrusion near the center. The smaller, coarser, northern granodiorite plug is 122m x 396m (Spencer and Paige, 1935).

Mineral Deposits

Mineral deposits are Laramide skarn and polymetallic replacement deposits in Paleozoic carbonate rocks along the margin of the Copper Flat stock (**table 5-1.29**). Two mines, one primarily a zinc producer and the other a magnetite iron skarn deposit, are the major deposits in the Copper Flat district. At the magnetite mine on the south and east margin of Copper Flat stock, polymetallic mineralization has replaced Oswaldo Formation rocks. The magnetite deposit is located on the northwest side of the stock and a prominent replacement zone in Oswaldo Formation surrounds the pluton. In this zone, sphalerite and magnetite bodies occur; magnetite typically is associated with sphalerite, but high-grade magnetite bodies without sphalerite are also present (Mullen and Storms, 1948). Iron deposits have been mined on the northwest side of Copper Flat stock; zinc has been mined on the south and east margin of the stock. In 1948, workings at the Copper Flat Mine consisted of a 122-m shaft, two 91-m shafts, several shallow shafts, and many small open pits (Mullen and Storms, 1948).

Copper Flat Mine exploited high-grade magnetite bodies lacking sphalerite. The ore is principally hematite with some magnetite and pyrolusite (Kelley, 1949). Gangue consists of kaolin, calcite, and serpentinous material. Limonite is abundant as a result of weathering, and malachite disseminations and coatings are common. Garnet was reported along the edges of the ore body. The massive ore zone is about 6m thick; a medium-grade (30-40 percent Fe) bed of banded ore and silicate at least 3m thick overlies the main ore bed. Ore was produced from an open pit about 67m long and 21m wide (Richter and Lawrence, 1983).

Fierro-Hanover district

Location, Mining History

Fierro-Hanover mining district, discovered in 1850, is about 19 km east of Silver City. From 1890 to 1980, 1.25 billion lbs Cu, more than 50,000 oz Au, more than 5 million oz Ag, more than 52 million lbs Pb, and 1.21 billion lbs Zn were produced (**table 5-1.30**). In addition, more than 3,600,000 short tons of iron ore were mined intermittently from the district from 1891 to 1945 (Hillesland and others, 1995; Hernon, 1949) and about 670 short tons of ore containing 18.9-25.9 percent Mn were produced from the Lost Treasure, Gold Quartz, Hamlett, and Old Claim Mines (Richter and Lawrence, 1983; Farnham, 1961).

Iron deposits in Fierro-Hanover district were identified during early development of copper mines at Fierro, Hanover, and Santa Rita (Kelley, 1949) (**figure 5-1.16**). Early in the mining history of the region, six major iron mines were operating. Early accounts mention lodestone cliffs and exposures of large high-grade magnetite deposits. Some iron-ore float may have been used as flux for nearby smelters before the 1880s; such production was known for twenty years after that date. After the railroad to Hanover was completed (1891), iron ore for flux was shipped to smelters as far away as Socorro and El Paso. In 1889 and 1893, New Mexico ranked 16th and 24th respectively in the U.S. for iron ore production, mostly from the Fierro-Hanover mines.

The greatest production of iron ore was from 1916 to 1931 (as much as 200,000 short tons/yr), when the ore was shipped to Pueblo, Colorado (Hernon, 1949). Large-scale iron mining ceased in 1931, but small amounts of ore were produced in 1936, 1937, 1942, and 1943-1945. Average iron grade of concentrates (near surface ore) was 51.0 percent Fe, 13.38 percent MgO, and 7.28 percent SiO_2.

During World War I, about 275 short tons of manganese ore was shipped from the district (Farnham, 1961). Production resumed during World War II, when 248 short tons containing 22.2-25.9 percent Mn were shipped to Deming. Most ore was mined from veins on Lost Treasure No. 2 claim. During the 1950s, mining produced from open cuts and underground sources. During that time, 51 short tons averaging 18.9 percent Mn of sorted ore were shipped from Gold Quartz claim and about 70 short tons containing 20 percent Mn were produced from Lost Treasure No. 2 vein. Ore produced at Lost Treasure was mined from an ore body near the southwest end of the vein (Farnham, 1961). These workings were idle by 1959.

From 1967 to 1994, Continental Copper Mine (**figure 5-1.17**) produced over 22,000,000 short tons ore containing 1.00-1.16 percent Cu and 0.41 percent Pb. Current reserves include 10,300,000 short tons of 0.92 percent Cu (open-pit), 3,600,000 short tons of 2.3 percent Cu (underground), and 80,000,000 short tons of 0.38 percent Cu as acid leachable chalcocite (Hillesland and others, 1994, 1995). Reserves include 20 percent iron as magnetite, 0.4 percent Zn, and minor gold and silver. Reserves at Hanover Mountain are estimated to be 80 million short tons of 0.38 percent copper (Hillesland and others, 1995).

District Geology

The district is centered around the north-trending, elongate, discordant Hanover-Fierro granodiorite porphyry intrusion. Sedimentary rocks that range in age from Upper Cambrian to Cretaceous are intruded by the pluton and quartz diorite sills, granodiorite and quartz monzonite dikes, and post-ore latite dikes. Spencer and Paige (1935) suggested that parts of the pluton are laccolithic. Schmitt (1939) suggested that the intrusion accompanied thrust faulting, which emplaced the older

strata. Aldrich (1974) described the Hanover-Fierro pluton as funnel-shaped and suggested that the granodiorite was forcibly injected into older rocks.

Barringer fault cuts the Continental deposit. Near the stock, fluids were injected along fractures, faults, and disturbed zones, which provided permeable channels that concentrated and directed mineralizing fluids (Hernon and Jones, 1968).

Mineral deposit types are porphyry-copper-related skarn, iron (magnetite) skarn, lesser zinc-lead skarn, and polymetallic vein and replacement deposits that resulted from intrusion of granodiorite porphyry into carbonate host rocks. Classic alteration associated with porphyry-copper deposits is not well developed at Continental Mine (Hillesland and others, 1995).

Mineral Deposits

Fierro-Hanover district contains one of the most important zinc deposits in New Mexico. The deposits are predominantly Laramide skarn types that are zoned (**figure 5-1.18**). Garnet replacement bodies occur nearest the pluton and grade to clinopyroxene-garnet and clinopyroxene zones. Base-metal zoning is generally observed. Copper is associated with garnet and clinopyroxene-garnet zones; lead-zinc is associated with the clinopyroxene zone. Proximal Zn-Pb skarn deposits occur around the southern lobe of the Hanover-Fierro pluton; distal Pb-Zn skarn deposits occur near faults and dikes (Jones and others, 1967; Meinert, 1987; Lueth, 1984; Turner, 1990; Turner and Bowman, 1993).

Major deposits in the district are owned by Cobre Mining Co., including the Hanover Mountain and Continental copper skarn deposits. Hanover Mountain deposit, a complex supergene chalcocite blanket in the Colorado Formation, is genetically related to Laramide intrusion of the Hanover-Fierro granodiorite stock (**table 5-1.30**; Richter and Lawrence, 1983). The deposit occurs at the north end of Hanover-Fierro stock, where the Barringer fault intersects north- and east-trending fractures. A zone of supergene copper minerals are present in the hanging wall of the Barringer fault. The fault is associated with structurally complex disseminated and replacement veins (Richter and Lawrence, 1983; Hillesland and others, 1995). At Hanover Mountain, chalcocite is the most economically important supergene mineral, and forms a uniform blanket 35 to 175 meters in extent (Hillesland and others, 1994, 1995). Cupriferous pyrite is the primary hypogene mineral. Chalcopyrite and sphalerite are common (**figure 5-1.19**).

Copper reserves at the Continental Mine are in the Lake Valley Limestone, Syrena Formation, and the upper Lake Valley Limestone beds north of the Barringer fault. Chalcopyrite is the main ore mineral; magnetite and iron-rich sphalerite are erratically distributed at the garnet-marble interface (Hillesland and others, 1994, 1995). Ore bodies are associated with the garnet-magnetite skarn downdip of the Barringer fault (**figure 5-1.20**). Supergene copper mineralization west of the main

pit within the Colorado Formation is associated with the Hanover Mountain porphyry. Hydrothermal fluids from the Hanover-Fierro stock migrated updip in adjacent sediments and were trapped by the impermeable Barringer fault zone, resulting in deposition of the copper skarn and replacement bodies (Hillesland and others, 1995).

Iron deposits are at or near the contact of the pluton and surrounding rocks. Ore bodies form in sedimentary rocks throughout the stratigraphic succession ranging from Bliss Sandstone to Fusselman Dolomite. Higher grade iron deposits occur in El Paso Limestone (Kelley, 1949), owing to greater porosity and lesser silicification. Ore bodies are lenticular masses, with average thicknesses of about 9m --deposits range to about 61m in thickness and to 305m in length (Hernon, 1949). Ore bodies contain the impurities limestone or wollastonite. Leaching and redeposition of copper may be localized at the contact between the ore and intrusive.

Minerals in the iron deposits include predominant magnetite, subordinate specularite, and minor chalmersite, pyrite, chalcopyrite, sphalerite, and sporadic molybdenite. Magnetite is altered to martite at or near the surface. Gangue minerals include unreplaced host rock, serpentine, and apatite (Hernon, 1949). Normal unoxidized iron ores contain about 0.6 percent Cu.

Pewabic Mine, on the eastern Hanover lobe (Hanover-Fierro stock), exploits pod-like sphalerite ore bodies that are uncontaminated by lead or copper and are localized at the intersection of a thrust fault and nearly vertical post-silicate northeast fault zones (Schmitt, 1939). Dimensions of the ore bodies are as much as 12m x 183 m. At Empire Zinc Mine, on the southwest margin of Hanover-Fierro stock, bodies as much as 305m x 37m x 9m (102,000 m^3) replace Lake Valley Limestone beds adjacent to granodiorite dikes (Paige, 1935). From 1905 to 1969, ore averaged 8.75 percent Zn. At Shingle Canyon Mines (owned by Cobre Mining Co.), Zn-Pb skarn deposits occur northeast of the stock in Abo Formation limy mudstone and limestone-pebble conglomerate beds in the footwall of the Barringer Fault (Anderson, 1957; Hernon and others, 1964). From 1939 to 1945, ore averaged 10.91 percent Zn, 3.25 percent Pb, and 0.11 percent Cu.

Lost Treasure and Gold Quartz group mines are the major source of manganese in the district. The deposit consists of replacement manganese bodies and lenticular fissure fillings in gently dipping, northeast-striking Magdalena Group limestones along two subparallel faults. Lost Treasure No. 2 vein is 0.6-1.5m wide and can be traced along strike for 244 m. Ore minerals have locally replaced limestone beds adjacent to the vein. The mineralized beds are 0.6-0.9m thick and extend about 0.6m into the hanging wall of the vein. Gold Quartz vein is traceable for 610m and is 0.6-1.8m wide. Pyrolusite and wad are the chief manganese minerals. Gangue minerals are iron oxides, manganiferous calcite, and quartz (Farnham, 1961).

Hamlett claims contain a small iron-manganese skarn deposit. Manganiferous iron ore

consisting of magnetite, hematite, and manganese oxides occurs in lenses along fractures and in irregular masses in contact-metamorphic deposits in Magdalena Group limestone (Farnham, 1961). Epidote, garnet, and pyroxene are alteration products.

Fleming district

Location, Mining History

Fleming (Bear Mountain) mining district is 9.5 km northwest of Silver City on the slopes of Bear and Treasure Mountains where fluorspar, iron, manganese, and silver in Laramide vein deposits (see Sutphin, this volume) are identified. The old silver-mining camp, Fleming, was active in 1882-1893, but was intermittent owing to Apache interference (Lindgren and others, 1910); after 1893, mining activity waned. Old Man Mine produced from about 1880s to 1893 and sporadically until 1949 (**table 5-1.31**; **figure 5-1.21**; **figure 5-1.22**). About $250,000 worth of silver were produced in the district from 1882 to 1905. In 1937, 222 lbs of Pb were produced. By then, about $300,000 worth of ore had been produced in the district, totaling 1,000 ounces Au, 300,000 ounces Ag, 10,013 lbs Zn, 450 lbs Cu, and 465 lbs Pb (Lasky and Wootton, 1933), as well as about 232 short tons of fluorspar (Williams, 1966). From 1916 to 1959, 1,860 metric tons of manganese ore were produced, containing about 30 percent Mn and 20 metric tons of concentrate containing 45.8 percent Mn (Farnham, 1961). The district has not been active in recent years (Anderson, 1957).

District Geology

In the vicinity of the Fleming Camp Mine on Treasure Mountain, Beartooth Quartzite is underlain by Fusselman Dolomite (Lindgren and others, 1910; Hernon, 1949). Ore is concentrated in irregular pockets in quartzite. Quartzite near the old stopes is traversed by numerous drusy veinlets of quartz and disseminated pyrite.

Bear Mountain Ridge, which hosts the Bear Mountain group mines, is a north-northwest-trending ridge composed of sedimentary rocks and a Precambrian core. Precambrian granite and gneiss are exposed along the central crest. In the southern crest, east-dipping sediments overlie granite; in the northern crest, west-dipping strata are exposed (Lindgren and others, 1910).

Mineral Deposits

Deposit types in Fleming district are listed in **table 5-1.32**). Silver-bearing polymetallic vein deposits at Fleming Camp are irregular oxidized bodies in Beartooth Quartzite, which overlies Fusselman Dolomite (Richter and Lawrence, 1983). Cerargyrite, native silver, and argentite are ore minerals. Gold, copper, and lead minerals are byproducts of silver mining. Gangue minerals include quartz, limonite, and pyrite. At Pauline Mine near Fleming Camp, silver-bearing minerals were mined from a quartz fissure vein in Precambrian granite (Richter and Lawrence, 1983).

Fluorite is deposited in El Paso Limestone in a 30-m-long fissure vein and as interstitial

material in breccia. At Ash Spring Canyon deposit, for example, the breccia zone is 2m wide within a vertical fault zone that strikes N.65°E. (Williams, 1966; Rothrock and others, 1946). Light green and moderately to coarsely crystalline fluorite partially replaces limestone wall rock. A grab sample of stockpiled material contained 26.3 percent CaF_2, 66.3 percent SiO_2, and less than one percent $BaSO_4$ and $CaCO_3$ (Williams, 1966). Stockpiled ore from Cottonwood Canyon prospect assayed 52.1 percent CaF_2, 46.4 percent SiO_2, 0.5 percent $CaCO_3$, and less than 0.1 percent $BaSO_4$ (Williams, 1966). At San Cristobal deposit, fluorite fills fissures in the pegmatite (footwall) - granite (hanging wall) contact zone. The vein trends N.36°W. and dips 73°SW (Williams, 1966). A sample of hand-sorted, stockpiled ore contained 92.1 percent CaF_2 and minor $BaSO_4$.

Discontinuous oolitic ironstone crops out in the Silver City and Piños Altos Mountains, near the base of the Bliss Formation. In Ash Spring Canyon, 0.6m of discontinuous oolitic hematite overlies 4m of basal conglomeratic sandstone and pink granite (Kelley, 1949). A grab sample contained 35.9 percent Fe, 0.30 percent P, 1.21 percent CaO, and 40.2 percent SiO_2.

Bear Mountain group of claims consists of replacement manganese deposits as irregular lenses of manganese ore replacing Oswaldo Formation limestone. Manganiferous ore crops out in a 120m x 76m area, which is crossed by two or more steeply dipping fracture zones. The fractures strike about N.25°E. Most mineralization occurs in limestone adjacent to the fracture zones. Locally, the limestone contains superimposed beds of ore with a thickness of as much as 18 m. Manganese minerals are mainly pyrolusite and wad; psilomelane is present near the surface. Calcite is the principal gangue mineral (Farnham, 1961).

Georgetown district

Location, Mining History

Georgetown (Mimbres) mining district (secs. 1, 2, 12, T. 17 S., R. 12 W., and secs. 6, 7, 18, T. 17 S., R. 11 W.) is located about 5 km east of Fierro, west of the Mimbres River, northeast of Santa Rita district, and south of Bear Canyon (**table 5-1.33**). In 1866, silver was discovered in the district (**figure 5-1.23**). Little mineral development took place until 1873, when a period of major production began that lasted until 1893. The mining camp was booming in 1875, but decline in the price of silver in the 1890s brought an end to mining (Anderson, 1957). Principal mines in the district were Naiad Queen, Commercial, and McGregor, all owned by the Mimbres Mining and Reduction Works Co. Both high-grade and concentrating ores (typically oxidized) were mined; low-grade material was sent to a concentrating mill along the Mimbres River. Little mining activity and practically no mineral production has taken place since the 1890s.

During the late 1970s and early 1980s, mine dumps were reprocessed and some gold and silver were recovered. Minor copper, lead, zinc, and gold were also produced in the district. Total production is estimated to be 3.9 million oz Ag (Lasky and Wootton, 1933; Richter and Lawrence, 1983).

District Geology

Paleozoic sedimentary rocks dip west-southwest at shallow angles (Jones and others, 1967). Several northeast-trending faults cut these rocks; nearly vertical porphyry dikes (71 Ma, $^{40}Ar/^{39}Ar$; McLemore, unpublished data, 1996) cut the limestone and shale units. The highly altered dikes are interpreted to be related to the Santa Rita and Hanover-Fierro intrusions (Lindgren and others, 1910). The eastern limit of the district is bounded by the northwest-trending Mimbres fault, which has juxtaposed semi-consolidated gravel deposits and Paleozoic sedimentary rocks (Hernon and others, 1964).

Mineral Deposits

Mineral deposits in the Georgetown district consist of silver-bearing vein and replacement deposits that are confined to irregular bodies in Fusselman Dolomite at the contact with Percha Shale. They are similar in mineralogy and stratigraphic position to silver deposits in several other districts, including Chloride Flat. The district coincides with an areoradometric U high and low K and Th values, which are characteristic of mineralized carbonate rocks in the southwestern New Mexico (see Pitkin, this volume)(**table 5-1.33**; Richter and Lawrence, 1983). Fusselman Dolomite limestone beds are typically silicified and locally vuggy, especially near dikes --the site of most ore bodies. Deposits occur in beds that dip 10°-20°S. Ore, localized near granodiorite porphyry exposures, was most valued for its cerargyrite content; native silver, argentite, smithsonite, bromyrite, pyragryrite, galena, and vanadinite were also present (Lasky and Wootton, 1933; unpublished data, NMBMMR). Pockets of cerussite and other silver minerals are localized. Prior to oxidation, argentiferous galena was probably the primary ore.

Ore shipments contained as much as 320 oz/short ton Ag, 18.3 percent Pb, and 33.6 percent Zn (unpublished data, NMBMMR). Dump samples contain as much as 0.7 percent V (Larsh, 1911). Early miners had little knowledge of the geologic relationships and did not examine faults for ore shoot offsets.

Gila Fluorspar district

Location, Mining History

Gila Fluorspar (Brock Canyon) mining district is located in the northern Piños Altos Mountains and Gila River Canyon about 8 km upstream from Gila (**figure 5-1.24**). Fluorite was produced from this district; no base- or precious-metals occur in economic concentrations.

Fluorspar was used as flux in the lead-silver smelters in Silver City (Gillerman, 1964).

In the 1880s, the Foster Mine had the first recorded fluorspar production in New Mexico. Several fluorite mines in the district operated during World War I, in the 1920s, and during World War II, and a fluorspar mill was operated at Gila during the 1940s. In 1944, average daily mine production was 50 short tons of fluorspar from Clum Mine (**figure 5-1.25**). The Federal fluorspar program was terminated at the end of World War II and mining waned. Fluorspar mining ceased in 1955. Except for a short revival in 1959, the district remained dormant until 1964 (Gillerman, 1964). By the 1970s, rising prices had stimulated new exploration, and Clum Mine was reopened (Ratté and others, 1979). Production has been recorded for 8 of the 13 mines and prospects in the district (Williams, 1966). Clum Mine produced about 29,000 short tons, averaging 52 percent CaF_2; Foster Mine produced about 4,000 short tons. Total production for the district amounted to 47,586 short tons, most from Clum and Foster Mines (**table 5-1.34**, **table 1-5**).

District Geology

In the district, Brock Canyon volcanic complex rocks consists of altered and unaltered latitic lava flows, volcanic breccia, and possible intrusive rocks that are unconformably overlain by silicic ash-flow tuffs in the north and Gila Conglomerate in the south. Age dates of lavas near the Clum Mine range from 30 Ma to 33 Ma (K-Ar, biotite; zircon, fission track; Ratté and others, 1979). In the central part of the district, the Gila River has exposed more than 304m of highly altered lava flows and tuffs of the Brock Canyon volcanic complex. The rocks have undergone acid-sulfate alteration and are pyritized, silicified, and altered to clays (McLemore, 1995a). The alteration is related to faulting or fracturing. In some fracture zones, bleaching and alteration of biotite has changed the color of the trachytic latite and andesite from dark to light gray or buff. Diversity of the lava flows, breccia, volcaniclastic rock, combined with the intense localized alteration, suggests that the Brock Canyon volcanic center is exposed at the mouth of Gila River Canyon (Ratté and others, 1979). Several quartz-fluorite-calcite fissure-filling veins cut both altered and unaltered rocks at the volcanic center. The veins are younger than the altered rocks, indicating the potential for mineralization at depth.

Mineral Deposits

Volcanic-epithermal fluorite vein deposits occur along northeast- to northwest-trending normal faults and fissures in volcanic rock (**table 5-1.34**.). Faults and fissures dip steeply to the east and west (Gillerman, 1964; Backer, 1974; McOwen, 1993). Foster vein strikes N.45°E. Many fault zones are brecciated; fluorite occurs as fissure filling, interstitial filling in breccia, replacements of fragments, and localized replacement of wall rock (Rothrock and others, 1947;

Russell, 1947a; McAnulty, 1978; Gillerman, 1964; Ratté and others, 1979). Quartz is commonly associated with fluorite, and silification and argillic alteration of the host rock is common. Fluid inclusion studies indicate that vein formation took place at 160-242°C by low-salinity fluids (0.7-5.0 eq. wt. percent NaCl) --characteristics typical of epithermal vein deposition (Backer, 1974; Hill, 1994).

Three distinct textures of fluorspar ore are reported: (1), coarsely crystalline, clear, translucent to transparent, massive, green, fissure-filling, with minor quartz; (2), fine- to medium-grained, containing inclusions of breccia and varying amounts of quartz; and (3), translucent to opaque, microcrystalline, white, red, gray, green, brown, or light blue, with disseminated quartz grains and local banding. The latter two textures contain as much as 30 percent silica and are unsuited for metallurgical grade, unlike the coarse-grained fluorite, which has been produced. Barite and pyrite are present locally.

At Clum Mine, fissure veins are developed along faults in the Brock Canyon volcanic complex. Fluorite occurs in two veins within fault zones (McAnulty, 1978). Clum vein strikes N.5°W. and dips 70°-80°SW.; east vein strikes N.25°-33°E. and dips 80°SW. Width of the mineralized fault zones are as much as 30 m, locally averaging one meter. East vein is smaller than Clum vein; finely crystalline white or red fluorite is present and coarse green fluorite is in veinlets. The workings consisted of a 90-m shaft and lateral developments of more than 300m (Williams, 1966). Two grab samples of stockpiled ore averaged 61.9 percent CaF_2, 23.5 percent SiO_2, 1.0 percent $CaCO_3$, and 7.4 percent rare-earth oxides ($R2O_3$, where R=rare earth).

Other mines and prospects in the district are similar, but smaller, than those at Clum Mine (**figure 5-1.26**). Samples have low gold and silver assays (Ratté and others, 1979). Stream-sediment samples have elevated concentrations of Ag, Ba, Co, Cu, Mn, Nb, Pb, Y, and Zn (Hassemer and Marsh, unpublished data, 1995; Ratté and others, 1979). The presence of intense alteration, geochemical anomalies, and veins suggests that the district has the potential for precious-metal vein deposits at depth.

Lone Mountain district

Location, Mining History

Lone Mountain mining district comprises low hills about 11 km southeast of Silver City. The district was discovered in 1871 by Frank Bisbee, for whom the historic Arizona copper-mining is named. After rich silver ore was identified, a mill was erected; mining and milling continued for a few years until ore ran out and the mines were shut down (Lindgren and others, 1910; Pratt, 1967). Except for a small amount of manganiferous iron produced during World War I, the area was dormant until 1920 when additional silver discoveries were made.

From 1921 to 1923, mining took place, and lead was produced along with silver. These later discoveries continued to be worked sporadically in the late 1940s (Pratt, 1967). In 1942, 30 short tons of manganese ore averaging 39.5 percent Mn were produced (Farnham, 1961), and from 1950 to 1955, 800 short tons of sorted ore averaging 29.1 percent Mn was shipped to the government purchasing depot in Deming. From 1955 until at least 1967, no additional silver was produced. By 1967, silver and manganese deposits were mined out and nearly all shafts were caved or unsafe (Pratt, 1967). Total mineral production from the Lone Mountain mining district is shown in **table 5-1.35**). Mineral deposit types in the district consist of carbonate-hosted silver-manganese deposits. Some of the deposits were mined for silver before manganese was produced.

District Geology

District geology near Lone Mountain is similar to that of nearby districts with small-scale production. Rock units in the region range in age from Precambrian to Recent; Lone Mountain district is composed of northeast-dipping Paleozoic and Mesozoic sedimentary rocks, primarily limestone and dolomite that were uplifted by a fault on the southwest side of the district (Lindgren and others, 1910). Hills rise about 159m above surrounding Quaternary colluvial and alluvial deposits. Precambrian granite crops out at the base of Lone Mountain (Pratt, 1967) and is overlain by about 1,220m of sedimentary rocks. From bottom to top, the sedimentary formations are Bliss Sandstone, El Paso Dolomite, Montoya Group, Fusselman Dolomite, Percha Shale, Lake Valley Limestone, Magdalena Group, Abo (?) Formation, Beartooth Quartzite, and Colorado Formation. On the eastern flank of Lone Mountain, Cameron Creek laccolith, an upper Cretaceous to Lower Tertiary pluton composed of biotite-quartz latite, is present (Lindgren and others, 1910). Later studies by Pratt (1967) found no evidence that the mineralization was spatially or genetically related to these intrusive bodies. Several dikes in the district range from quartz latite to basalt in composition. Most are only a meter or so wide; a few have an inferred length of as much as 1.2 km.

Mineral Deposits

The distinction between the silver and manganese deposits in the district is not clear; most were mined out without documentation (Pratt, 1967). Mines that produced silver during the early mining period later produced manganese. Many silver and manganese deposits occur in cross-cutting fractures in carbonate rock (Pratt, 1967). Some brecciation occurs along the fractures, and limestone has been locally silicified (Lindgren and others, 1910). Ore bodies do not indicate strict stratigraphic control that is present in many silver deposits in the region. In the Lone Mountain area, silver deposits are scattered throughout the Fusselman Dolomite; one vein extends into

Upham Dolomite and Aleman Formation. **Table 5-1.36** lists mineral occurrences in the Lone Mountain district.

Cerargyrite was the most common ore mineral, but curved bundles of native silver wire were the richest ore (Lindgren and others, 1910). Argentite was reported as a primary ore mineral; native copper was also reported (Pratt, 1967). Limonite was plentiful as an oxidation product of pyrite. Other minerals seen in fractures or on the mine dumps include quartz, calcite, dolomite, and small amounts of anglesite, cerussite, willemite, and malachite (Pratt, 1967). Mineralized veins were narrow (0.6-1.5m wide); ore veins were up to 2.4m thick. Veins were lenticular, but contained rich silver ore (Lindgren and others, 1910).

Manganese deposits are irregular, pod-like bodies that occur along north-trending, vertical fracture zones cutting and replacing Lake Valley Limestone below the basal shale member of the Oswaldo Formation (Magdalena Group) (Farnham, 1961). Ore bodies range to 18m in length and are 0.3-1.8m wide. Some fractures contain two or more ore bodies separated by tens of meters of unmineralized, or sparsely mineralized, material. Most ore stretches along the fractures, but adjacent limestone beds are locally replaced. Primary ore minerals are pyrolusite and wad; principal gangue minerals are iron oxide, jasper, and black and white calcite.

These manganese deposits could be a low-grade iron resource. The deposits are described as irregular masses of manganiferous hematite in shattered limestone on the flanks of Lone Mountain. Ore consists of hematite and pyrolusite with some wad, magnetite, calcite, and jasper. Ore from the Mineral Mountain group contained about 35 percent Fe and 15 percent Mn (Harrer and Kelly, 1963). Concentration of detrital or placer magnetic iron oxides occur in stream cobbles (Pratt, 1967). The material is derived from Gila Conglomerate, the ultimate source being magnetite in iron skarn deposits adjacent to Hanover-Fierro stock.

Piños Altos district

Location, Mining History

Placer gold was discovered in 1860 in the Piños Altos mining district, Pinos Altos Mountains, 13 km northeast of Silver City. Later that year, Pacific vein, the first lode, was discovered in the district. Within two years, 30 mines were worked by 300 men (Lindgren and others, 1910). Mining continued only as the Civil War and plundering by Apaches would allow. During World War I, Piños Altos produced considerable tonnages of zinc ore containing sphalerite, chalcopyrite, and galena (Waldschmidt and Lloyd, 1949).

Pacific Mine was the largest producer, with production of over $1 million by 1905 (Lindgren and others, 1910). Placer gold accounted for 7.5-12.0 percent of the area's past production. By 1940, the district had yielded over $8 million in gold, silver, copper, lead, and

zinc (Wells and Wootton, 1940).

In 1948, Cyprus Piños Altos skarn was discovered by the U.S. Mining, Smelting, and Refining Co. Exxon Minerals drilled 213 holes in the early 1970s, and Boliden Minerals drilled 135 additional holes in 1982, as well as driving 2,423m of development headings. Boliden estimated reserves at 1,015,979 short tons of 4.96 percent Cu, 2.54 percent Zn, 3.482 oz/short ton Ag, and 0.024 oz/short ton Au. Cyprus Metals acquired the mine in 1987, and began a joint venture with St. Cloud Mining Co. (Osterberg and Muller, 1994). The joint venture ended in 1989, and Cyprus continued until 1995. Production from the mine, as of mid-1995, totals 661,238 short tons ore, containing 56,886,468 lb Cu, 18,515 oz Au, 1,805,180 oz Ag, and 31,210 lb Zn. Production from the district is estimated as 59.5 million lbs Cu, 169,000 oz Au, 2.6 million oz Ag, 6 million lbs Pb, and 64 million lbs Zn. Some iron ore was also produced (**table 5-1.37**; **table 5-1.38**).

In Piños Altos district, Late Cretaceous andesitic volcanic rocks rest unconformably on Cretaceous clastic rocks of the Beartooth Quartzite, Colorado Formation, and Paleozoic carbonate rocks of the Magdalena Group (Osterberg and Muller, 1994). Sedimentary and volcanic rocks are intruded by Piños Altos stock, a medium grained quartz monzonite. The stock is part of the 70 m.y.-old Piños Altos intrusive complex, which consists of the stock and related mafic to intermediate intrusives on its periphery (McKnight and Fellows, 1978). Mineral deposits lie within Piños Altos stock and in the sedimentary and volcanic rocks in close proximity to the stock.

The braided structural pattern of the northwest- and northeast-trending faults is characteristic of mineralized porphyry systems (McKnight and Fellows, 1978). Northeast-trending fissure veins indicate northwest-southeast extension. Many are exposed both in the stock and host rocks and are mineralized. The district is divided into several structural blocks by east-trending faults that cut the northeast-trending faults.

Mineral Deposits

Lode deposits are Laramide vein deposits in quartz monzonite and diorite intrusives and lead-zinc skarn deposits, with lesser copper skarn deposits, in limestone. Replacement and skarn deposits in Magdalena Group limestones was the source for most past production (McKnight and Fellows, 1978). The most prolific mine was the Cleveland Mine west of Piños Altos stock, which produced zinc, lead, copper, silver, and gold from a polymetallic replacement deposit.

The paragenetic sequences of mineral deposition of base-metal and precious-metal vein and replacement deposits are: (1), early pyrite and pyrite-marcasite; (2), initial episodes of copper deposition as chalcopyrite; (3), zinc as sphalerite succeeding chalcopyrite; and (4), copper mineralization as chalcocite, bornite, and chalcopyrite accompanied by silver deposition

(stromeyerite and native silver) and bismuth.

Cyprus Piños Altos skarn deposits occur in calc-silica altered Lake Valley Limestone, Oswaldo Formation, Syrena Formation, and Beartooth Quartzite (**figure 5-1.27**). These units are overlain by Colorado Formation and Cretaceous-Tertiary andesite and andesitic breccia. The central part of the Piños Altos Mine is occupied by diorite intrusive rock surrounded by a breccia body with diffuse and poorly defined contacts. Quartz monzonite fragments do not occur within the breccia, but quartz monzonite dikes and sills cut both the breccia and related silica-pyrite alteration. Ore includes chalcopyrite and bornite, and minor chalcocite, covellite, native Cu, wittichenite, sphalerite, galena, arsenopyrite, and native Ag. Gangue minerals include quartz, kaolinite, sericite, calcite, magnetite, hematite, goethite, and limonite (Osterberg and Muller, 1994).

Alteration and mineralization consisted of thermal-metamorphic, metasomatic, and retrograde stages. During the thermal metamorphic stage, alteration was dependent on the composition of original host rocks (McKnight and Fellows, 1978). Limestone and dolomite recrystallized. If silica was available, wollastonite formed in argillaceous and silty limestones. Many calc-silicate skarn minerals formed. Siltstone, mudstone, and shale were metamorphosed to hornfels.

The metasomatic stage produced a lesser variety of skarn minerals. Andradite, quartz, and calcite make up most of the rock, and magnetite, pyrite, specularite, diopside, and base-metal sulfides occur in lesser amounts. Garnet replaces some limestone beds *en masse*. Sulfides are localized throughout the garnetized zones, and some sphalerite occurs in marble outside of the skarn zone.

Minerals produced during retrograde alteration are usually hydrous phases, such as chlorite, clay, actinolite, talc, and sericite. The paragenetic sequence for the Cyprus Piños Altos deposit shows that calc-silicate minerals formed early, and were followed by iron oxides and varieties of copper, zinc, silver, lead, and bismuth sulfides.

At Lady Katherine Mine north of Cleveland Mine, fissure veins contain chalcopyrite and minor sphalerite, and occur with pyrite in Magdalena Group limestone that has been altered to the skarn-assemblage minerals (garnet, diopside, actinolite, and calcite; McKnight and Fellows, 1978). Exxon prospect, northeast of Lady Katherine Mine, is a skarn deposit associated with the Piños Altos stock. McKnight and Fellows (1978) describe the results of drilling exploration at the prospect, where copper-zinc-silver sulfide mineralization in Magdalena Group, Lake Valley Limestone, and Lower Paleozoic rocks was located.

Pacific Mine is a polymetallic fissure-vein deposit. Fissure veins trend N.60°E. and extend

for over 1,220 m; they cut fine-grained diorite porphyry. Vein width averages 0.8 m, but may reach 3.7 m. The quartz vein contains calcite, barite, and rhodochrosite, with lesser amounts of pyrite, chalcopyrite, galena, and sphalerite. Pyrite and chalcopyrite are typically more abundant than galena and sphalerite. Diorite porphyry wall rocks are altered to chlorite and sericite for distances of 2-4 cm from the vein. Gold is associated with pyrite; galena is not argentiferous.

Between Sycamore and Bear Creeks in the Piños Altos Mountains, oolitic hematite deposits in Bliss Sandstone are exposed for a length of over 2,440 m. The basal, oolitic-hematite-bearing part of the Bliss Sandstone in Sycamore Canyon contains 12 beds in about 45 vertical ft (Harrer and Kelly, 1963).

Gold placer deposits cover an area of about 3.9 km^2 in Bear Creek, Rich, Whisky, and Santo Domingo Gulches (Johnson, 1972). The richest parts of the placers were probably exhausted a few years after discovery (1860), but the placers were worked subsequently. Gold was derived from eroded, oxidized base metal-gold-silver vein and replacement deposits in the area (Johnson, 1972). Placer mining was hampered by intermittent water supplies. Most placering was on a small scale by individuals using pans, rockers, and sluices. In 1935 and 1939-1942, Bear Creek and Santo Domingo Gulches were dredged. Assays of placer gravels found as much as 40 percent heavy mineral sand, containing 83 percent magnetite, 3 percent garnet, 8 percent hematite, and $9.30 per short ton Au ($20.67 per oz Au).

Santa Rita district

Mining history, Location

Santa Rita (Chino) copper deposit located east of Hurley is the largest mineral producer in the study area (**figure 5-1.28**). Santa Rita copper deposit was initially discovered by Native Americans, who used it as a source for implements and weapons. Later, mining by the Spanish was inconsequential until about 1798, when Apaches informed Colonel Manuel Carrasco about copper deposits at Santa Rita. Carrasco persuaded Francisco Manuel Elguea to form a partnership, and they were issued a land grant --Santa Rita del Cobre Grant. By 1804, Elguea bought out Carrasco and began mining the copper at Santa Rita in earnest, having found a ready market for copper in Mexico City. Raids by natives and depletion of high-grade ore kept mining operations small. At that time, no process for economically extracting copper from the underlying low-grade sulfide ore existed. In the 1880s, attempts were made to use more modern mining and processing methods at the deposit. In 1881, a stamp mill and a smelter were built, and in 1883 the first exploratory diamond-drill holes were drilled. However, high transportation costs brought an end to this mining venture. In 1899, the Santa Rita Mining Co. bought the property and expanded the underground workings to explore for more ore, but it never found the main ore body.

In 1904, John M. Sully arrived at Santa Rita and recognized the similarity of ore at Santa Rita to that mined at Bingham Canyon, Utah. Sully thoroughly explored the area and attempted to obtain backers for his venture, the Chino Copper Company (Sully, 1908). In 1908, Chino Copper Company took over Santa Rita Mining Company. In 1910, production began (**figure 5-1.29A**, **figure 5-1.29B**). The first concentrator mill was erected at Hurley in 1911; flotation concentration was added in 1914 (Hodges, 1931). That effort and those that followed have been successful at large-scale and high-volume production.

Santa Rita (Chino) Mine has produced more than 9.08 billion lbs Cu, 500,000 oz Au, and 5.36 million oz Ag; some molybdenum and iron ore were produced from 1911 to 1993 (**table 1-3**; **table 1- 4**; **table 1-7**; Long, 1995). In 1993, the mine produced 108,568,000 short tons of 0.73 percent Cu (Giancola, 1994). In 1995, reserves were estimated as 315.4 million short tons of concentrator ore with a grade of 0.67 percent Cu, and 720.5 million short tons of leach ore with a grade of 0.24 percent Cu (Robert North, Phelps Dodge Corp., written communication, October 1995). Some iron ore was produced in 1943-44.

District Geology

Santa Rita consists of Basin and Range structures. The area lies near northwest-trending Paleozoic and Mesozoic sedimentary rocks and Tertiary volcanic rocks within a fault-bounded horst (**figure 4-1.4**). These sequences are covered to the north by Cenozoic volcanic and sedimentary rocks (Rose and Baltosser, 1966). Within the horst, Paleozoic and Mesozoic sedimentary rocks are exposed in a 40 km x 16 km broad, shallow syncline. Cretaceous rocks are exposed in the central part of the range, and Lower Paleozoic rocks are exposed to the northeast and west.

Emplacement of the Santa Rita stock took place in Laramide time; age determination of the stock show that it ranges from 55-56 m.y. (Schwartz, 1959; McDowell, 1971; Robert North, Phelps Dodge Corporation, written commun., October 1994). It consists of granodiorite to quartz monzonite porphyry similar to rock in the Hanover-Fierro and Copper Flat stocks and may have been derived from similar sources. Intrusion was followed by hydrothermal alteration, sulfide mineralization, supergene enrichment, and intrusion of granodiorite porphry that affected the nearby rocks as well as the stock. Mineralization was aided by cooling fractures.

Mineral Deposits

Santa Rita is the largest porphyry-copper deposit in New Mexico. Copper sulfides occur in the highly fractured granodiorite and nearby sedimentary rocks, including the mineralized Abo Formation limestone, Beartooth Formation quartzite, and Colorado Formation shale (**figure 5-1.28**). Primary structures and textures in the sedimentary rocks and the intrusion are

mostly obliterated. Several periods of supergene enrichment have concentrated the ore (S.S. Cook, Phelps Dodge Mining Co., oral commun., October 1994).

Adjacent copper skarn deposits are also of economic importance in the district. Potassic, phyllic, argillic, and propylitic alteration zones are present, but are not always concentric (Nielsen, 1968, 1970). Skarn deposits on the northwest and southeast of the stock are locally attributed to the underlying stock (Paul Novotny, Phelps Dodge Mining Co., written commun., 1994). Whim Hill breccia, a barren deposit located at the cupola of the intrusive, is bounded on all sides by potassically altered, but barren, granodiorite (Paul Novotny, Phelps Dodge Mining Co., written commun., 1994; Rose and Baltosser, 1966).

Early production was from disseminated supergene chalcocite ore in diorite sills within the stock, and from Colorado Formation shale. Chalcocite-pyrite skarn type ore became of increasing economic importance in the Oswaldo and Syrena Formations (Neilsen, 1968, 1970). Supergene minerals include chalcocite, chrysocolla, covellite, cuprite, native copper, malachite, and azurite. Primary minerals in the porphyry ore are chalcocite, bornite, and molybdenite; those in the replacement ore are chalcopyrite and magnetite. The grade of copper ore decreased as mining progressed. In 1912, grade was over 2 percent copper. By 1925, it had fallen to 1.5 percent. In 1948, the grade was less than one percent (Gibson and Trujillo, 1966; Wunder and Trujillo, 1987), and in 1980, the grade averaged only 0.81 percent.

SAN FRANCISCO CANYON

San Francisco district

Mining history, Location

San Francisco district lies in northwestern Grant County and southwestern Catron County, and is several km from the Arizona stateline. The district has been little mined; in 1980, no mining or patented mine claims existed in the district. Ratté and others (1982) cite evidence of past prospecting activity, however.

District Geology

The district lies within the Potholes Country graben, and includes middle Tertiary volcanic rocks, mainly andesitic and basaltic lava, and lesser rhyolite flow and pyroclastic rocks. These units are covered by Gila Conglomerate. The graben is bounded by northwest-trending faults, and is estimated to be downdropped 180-240m (Ratté and others, 1982). Potholes Country rhyolite was extruded from a vent at the southern edge of the graben; rhyolite plugs, flows, and pyroclastics are high in silica and potassium.

Mineral Deposits

None of the mineral occurrences in the district are located within the Mimbres Resource Area. Placers along the San Francisco River in Arizona have produced gold (North and McLemore, 1986) and several prospects are present north of the river in Catron County. Quartz veins as much as 9m wide are present within and peripheral to the Potholes Country graben. Locally the rocks are hydrothermally altered, especially near extrusive vents where manganese and iron oxides coat fractures and the rhyolite has been bleached and silicified. Silicified zones in rhyolite in nearby areas are anomalous in gold and silver (Ratté and Lane, 1984). Silica, potassium, rubidium, strontium, and niobium content of the rhyolite is suggestive of molybdenum, tin, and tungsten mineralization. Anomalous Mn, Ag, Au, Cu, Mo, Be, W, Sb, Ba, and B values have been found in vein material in rhyolite intrusive rocks, and may be indicative of mineralization at depth (Ratté and others, 1982).

Major porphyry copper deposits in Laramide intrusive rocks are present about 24 km southwest of the district. Pre-Tertiary rocks exist in exploratory drill holes several km north of the district.

SUMMIT MOUNTAINS

Steeple Rock district

Mining history, location

Steeple Rock mining district is in the Summit Mountains, extending from Grant County into Greenlee County, AZ (**figure 5-1.30**), and includes Carlisle, Duncan, Twin Peaks, Hells Hole, Bitter Creek, and Goat Camp Springs subdistricts. Exploration was reported in 1860 when the military dispatched troops from Ft. Thomas (near Duncan, Ariz.) to assist miners in the area with Apache interference (Russell, 1947a). Production began in 1880 when a 20-stamp amalgamating mill was erected at the Carlisle Mine. By 1886, the mill was enlarged to 60 stamps. Most mines in the district were under development by 1897, but production prior to 1904 is uncertain. Many mines closed in the early 1900s (**figure 5-1.31**). Carlisle Mine was the largest producer; about 112,000 short tons produced prior to 1904 is attributed to the Carlise Mine. An estimated $10 milliion in gold, silver, copper, lead, and zinc have been produced since 1880. In addition, about 11,000 short tons of fluorite and 2,000 short tons of ore containing 74,500 lbs of manganese were produced (McLemore, 1993b; McAnulty, 1978; Griggs and Wagner, 1966; Farnum and others, 1961) (**table 5-1.39**).

In 1933, gold prices rose from $20.67 per oz to $35.00 per oz, and many of the mines were re-examined for gold potential. From 1934 to 1942, total production amounted to about 30,000 oz Au and over one million oz Ag (Griggs and Wagner, 1966). Most came from East Camp Mines.

In 1942, all silver and gold mines were closed when all production in the U.S. was in base metals for the war effort. After 1947, production from this district was minor and sporadic.

From 1970 to the present, gold exploration has intensified. Drilling and production, mainly for silica flux, has taken place. Queenstake Resources, Ltd. estimated reserves at the Jim Crow, Imperial, and Gold King veins as 155,535 short tons of ore, averaging 0.11 oz/short ton Au and 3.45 oz/short ton Ag (Queenstake Resources, Ltd., press release, 4/2/87). In the 1980s and 1990s, Biron Bay Resources, Ltd., in joint venture with Nova Gold, Ltd., drilled along the Summit vein and estimated reserves as 1,450,000 short tons of ore grading 0.179 oz/short ton Au and 10.26 oz/short ton Ag (Petroleum and Mining Review, May 1992, p. 2). None of the deposits have been mined.

District Geology

The district is on the southern Mogollon-Datil volcanic field on the northern edge of the Burro uplift near the intersection of the Texas and Morenci lineaments (**figure 1-4**; McLemore, 1993b). In the district, a sequence of 34-27 m.y.-old andesite, basaltic andesite, and dacitic lava flows are interbedded with andesitic to dacitic tuff, sandstone, volcanic breccia, and rhyolite ash-flow tuff. The sequence was intruded by rhyolite plugs, dikes, and domes that are 33 Ma and 28-17 Ma. Faulting produced a series of northwest-trending half-grabens and horsts; bedding dips to the northeast (Griggs and Wagner, 1966; Powers, 1976; Biggerstaff, 1974; McLemore, 1993b). Rhyolite dikes, plugs, and domes were emplaced along faults and locally were cut by younger faulting. Most faults are high-angle normal faults and are well exposed owing to their resistance to erosion (they are filled with quartz veins and/or silicified, brecciated country rock). Faults exhibit oblique-slip offset locally, as shown by offset dikes or veins (Griggs and Wagner, 1966; McLemore, 1993b).

Mineral Deposits

Mineralization at Steeple Rock district is of the volcanic-epithermal precious- and base-metal types in fissure veins along faults. Five deposit types occur: (**table 5-1.40**): (1) base metals with precious metals, (2) precious metals, (3) copper-silver, (4) fluorite, and (5) manganese. In addition, high-sulfidation (quartz-alunite) gold deposits may occur in areas of acid-sulfate alteration; no production has occurred (McLemore 1993b). District-wide zoning of fissure veins is present. Base-metal vein with significant amounts of gold and silver occur along

the Carlisle fault and may represent the center of the district. Precious-metal veins occur outward from the base-metal veins, along northwest- and north-trending faults. Locally the veins grade into trace base-metal sulfide deposits, and precious-metal veins grade upward to copper-silver veins lacking gold. Fluorite and manganese veins are present along the fringes of the district (McLemore, 1993b). Epithermal veins are low-sulfidation (quartz-adularia) veins that are structurally controlled and deposited by low-salinity (less than 5 eq. wt. percent NaCl), slightly acidic to neutral pH fluids at temperatures of homogenization between 240°C and 325°C and shallow depths between 360m and 1300m (McLemore, 1993b; McLemore and Clark, 1993). Areas of acid-sulfate alteration are cut by epithermal veins and superimposed and surrounded by argillic to chloritic alteration (McLemore, 1993b). These areas of alteration were formed in a magmatic-hydrothermal environment, as evidenced by mineral, chemical, and temperature zonation, preseved textures, sulfur isotopic data, and ages. Some contain anomalous concentrations of Au, and have potential for high-sulfidation (quartz-alunite) gold deposits.

MINERAL OCCURRENCES AND MINING DISTRICTS OF HIDALGO COUNTY

by

Virginia T. McLemore, NMBMMR,

and David M. Sutphin, USGS

INTRODUCTION

Hidalgo County was established in 1919 from the southwestern part of Grant County. Prospecting began in 1870, but no significant production occurred until the arrival of the railroad in Lordsburg in 1880. By 1930, all 13 mining districts were discovered (table 1-2). Minerals produced in Hidalgo County from 1880 to 1994 were copper, lead, zinc, silver, and gold; most of the production value came from the Lordsburg district (table 5-2.1; Elston, 1960, 1965). Until 1970 when most production ceased, Hidalgo County ranked second (behind Grant County) in base- and precious-metal production in New Mexico (Elston, 1960, 1965). McGhee Peak mining district is the 8th largest, and Lordsburg mining district is the 10th largest, lead and zinc producing districts in New Mexico (McLemore and Lueth, 1995)(figure 1-12). Copper-gold veins were mined in the Lordsburg district for silica flux in 1990-1994. Current production includes silica sand and clay for use as smelter flux (Brockman and Pratt Mines), and sand and gravel for use in aggregate (Hatton and others, 1994). Hidalgo (or Playas) smelter was built in 1979 in the Animas Valley and is currently refining ores containing copper, silver, gold, and sulfuric acid from ore mined at Phelps Dodge mines in New Mexico and Arizona (Hatton and others, 1994).

ALAMO HUECO-DOG MOUNTAINS

Antelope Wells-Dog Mountains District is within the Alamo Hueco-Dog Mountains. Manganese and associated uranium were mined.

Antelope Wells-Dog Mountains District

Location and Mining History

Antelope Wells-Dog Mountains mining district is in the Alamo Hueco, White, and Dog Mountains in the southwestern New Mexico panhandle; Alamo Hueco Mountains WSA lies north of the district. In 1954, T.C. Boyles shipped 5.6 long tons of 37.9 percent Mn from the Rusty Ruthlee Mine to Deming (Farnham, 1961), initiating development in the district. Manganese is widespread in epithermal vein deposits (table 5-2.2). The only other identified mineral deposits in the district consist of small showings of uranium, which occur in fault breccia. Two exploration pits, each approximately 3m deep, were dug in 1954 at the Opportunity claims in the Dog Mountains where there is a small occurrence of radioactivity. About 2 short tons of ore were milled, but the uranium was intimately associated with opal and quartz and could not be separated

(Reiter, 1980). At one site, a 1.8-m–deep prospect pit was dug in travertine, but no deposits of commercial value were identified.

District Geology

Alamo Hueco, White, and Dog Mountains consist of layered Tertiary volcanic rocks overlying a unit resembling the Timberlake Fanglomerate containing limestone and sandstone cobbles (Zeller, 1959; Zeller and Alper, 1965;, Deal and others, 1978; Reiter, 1980). Ash-flow tuffs of the Alamo Hueco Mountains are outflow sheets from nearby calderas. Northwest and north-northwest-trending faults are pervasive in the range. The district borders the eastern San Luis caldera, dated at 23-24 Ma (Deal and others, 1978) and is associated with a magnetic low and a general gravity low between two gravity highs (see Abrams and Klein, chapter 3, this volume). The area also coincides with moderate aeroradiometric K, U, and Th anomalies (see Pitkin, chapter 3, this volume). Analyses of stream-sediment samples show scattered high anomalies of As, Be, Bi, Cd, Cr, Cu, K, La, Mn, Mo, Nb, Th, Y, and Zn (Hassemer and Marsh, unpublished data, 1995).

Mineral Deposits

Epithermal veins of manganese and uranium have been identified in the Alamo Hueco and Dog Mountains (**table 5-2.2**). At Opportunity claims, uranium occurs in a highly fractured, opalized zone at the intersection of two normal faults in volcanic rock (Everhart, 1957; McLemore, 1982, 1983b). Samples assayed 0.02-0.77 percent U_3O_8 (McLemore, 1982, 1983b). Mineralized breccia was traced to the northwest along strike for 183 m. Radioactive veins of opal and quartz approximately 2-5 cm thick surround angular clasts of Tertiary rhyolite of the Oak Creek and Gillespie Tuffs. This opal is gathered by mineral dealers and collectors.

Jasper and opaline quartz veins are found in several major fault zones in the southern part of the area (Reiter, 1980). Jasper veins and pods up to 3m long were identified at the intersection of two faults in sec. 16, T.33S., R.14W. The veins have not been analyzed for uranium content.

Extensive travertine deposits with associated manganese occur in tuffs of the Bluff Creek Formation in the southern part of the area (Reiter, 1980). Two travertine beds, each about one meter thick, are separated by a thin sandstone unit. Psilomelane bands up to several cm thick form the lowermost parts of the travertine. Prospect pits have developed the deposit, but production, if any, is unknown. Guano is found in a cave in sec. 16, T.33S., R.14W. (Reiter, 1980).

ANIMAS MOUNTAINS

The Animas Mountains contain the Gillespie and Rincon Districts.

Gillespie District

Location, Mining History

Gillespie (Red Hill) mining district is located in the Animas Mountains about 48 km southwest of Hachita and 35 km south of Playas (**figure 5-2.1**). Cowboy Spring WSA is south of the district.

Gillespie district was discovered in 1880. From 1880 to 1950, a minor amount of Au, Ag, Cu, Pb, and Zn was produced from volcanic-epithermal veins (**table 5-2.3**; Lasky and Wootton, 1933; Elston, 1965) (see Sutphin, chapter 2, this volume). Most of the ore was produced from the Red Hill Mine. Between 1905 and 1950, ore grades at Red Hill Mine averaged 0.01 oz/short ton Au, 4.06 oz/short ton Ag, 0.18 percent Cu, 17.92 percent Pb, and 0.91 percent Zn. Workings consist of two inaccessible shafts and a 122-m main shaft with two levels, having about 305m of drifts and crosscuts.

No production has been reported from Gillespie deposit. Presently, the workings consists of shafts as deep as 31m and numerous pits (Zeller and Alper, 1965). A visit to the district in 1994 indicated that development had taken place in at least one of the shafts at Gillespie Mine as late as 1991.

In 1960, fluorspar was discovered at the Winkler anticline in the Athena prospects (known then as the Volcano claims) southeast of the district. Several trenches and four shallow test shafts were dug, 15-30-m deep percussion holes were drilled, and extensive sampling and geochemical testing was performed. A resource of about 150,000 short tons containing 25-35 percent CaF_2 was identified; copper and silver are potential byproducts. A mill was erected in sec. 34, T.30S., R.18W. (**figure 5-2.2**) and fluorspar was shipped in the 1970s (Phil Young, local rancher, oral commun., 4/19/94). However, ore was low grade and difficult to concentrate, so the mill was unsuccessful. Manganese was also produced from several veins (**table 5-2.4**). Approximately 276 long tons of 22-45 percent Mn were produced. Tungsten occurs in these veins, but there is no reported production (Dale and McKinney, 1959).

District Geology

Andesitic and basaltic volcanism and intrusion of intermediate composition stocks took place in Laramide time, and was followed by large-scale volcanism and formation of major ash-flow calderas in Oligocene time (Elston and others, 1979). The district lies at the junction of the Animas Peak, Geronimo Trail, and Juniper calderas. In some of these calderas, such as the

35-Ma Juniper caldera, porphyry stocks were intruded into the caldera. A major structural feature of the district is Winkler anticline.

Stream-sediment geochemistry anomalies include Ag, As, Be, Co, K, La, Mn, Nb, Th, U, Y, and localized Au, Ti, and Sn (Hassemer and Marsh, unpublished data, 1995). The area is characterized by low gravity, high magnetic, and low aeroradiometric K, U, and Th (see Abrams and Klein, and Pitkin, chapter 3, this volume).

Mineral Deposits

Mineralization consists of volcanic-epithermal veins of fluorite, gold-silver-lead, and manganese. Four types of veins occur: silver-bearing (Gillespie Mine), fluorspar (Winkler anticline deposits), oxidized lead-silver (Red Hill Mine), and manganese (Combined Minerals Corporation mine). Silification is common near the veins.

The largest mine in the district is the Red Hill Mine (**figure 5-2.3**), where a northwest-trending oxidized lead-silver vein cuts altered Tertiary quartz latite ash-flow tuff. The vein strikes N. 77° W., dips 75°-85° NE, and consists mainly of cerussite, minor anglesite, and a small amount of locally argentiferous residual galena (Zeller and Alper, 1965; Elston, 1965). Malachite, chrysocolla, smithsonite, sphalerite, and wulfenite are also found. Quartz and calcite are gangue minerals, with minor fluorite.

Gillespie Mine is situated on a small vein that strikes N. 65° E. and dips 65° NW (**figure 5-2.4**). Host rocks are altered Horquilla Limestone and Earp Formation calcareous siltstone. Azurite and malachite occur on the dump; linnearite was found in a vug from a prospect pit. Calcite, quartz, siderite, and minor fluorite are gangue minerals. Silicification is common.

Winkler anticline fluorspar deposits occur as scattered pods and breccia cement in irregular fluorite-jasperoid replacement mantos. Limestone units of the Pennsylvanian Horquilla Limestone and Cretaceous U-Bar Formation are host rocks. Formation of the Winkler anticline produced fractures in the host rocks that allowed hydrothermal solutions to enter. Dissolution breccia is present, with fluorite filling the open-spaces; jasperoids are common. Clear, white, green, and purple fluorspar were identified at the workings, with a gangue of quartz and calcite. Locally, trace sulfides occur with fluorspar. Texas Lime Co. drilled several holes in 1970-1971 and delineated estimated reserves of 150,000 short tons of 25-35 percent fluorite (Scott, 1987). Material remains at the site after the attempted production.

Manganese veins are scattered throughout the district (**table 5-2.3**; Zeller and Alper, 1965). Volcanic rocks and quartz monzonite typically host the veins, which consist of manganese oxides, calcite, barite, fluorite, and rare quartz (Zeller and Alper, 1965). Ore produced from the Combined Minerals Corporation Mine contained 40-45 percent Mn and less than 0.25 percent

combined copper, lead, and zinc. Veins occur along normal faults that strike N.14°E.-N.21°W., have steep dips, and are typically less than one meter wide and several tens of meters long. The manganese-fluorite veins at the Ridge (Hodget) Mine contain as much as one percent WO_3 and 39 percent Mn, but recovery of tungsten from manganese ore is not yet economically feasible (Dale and McKinney, 1959; unpublished data, NMBMMR). The veins, less than 0.5m wide, occur in a zone less than 4.6m wide and 48m long within rhyolite (Dale and McKinney, 1959; Williams, 1966).

Rincon District

Location, Mining History

Rincon (Animas) mining district is located in the northern part of the Animas Mountains southwest of Animas (**figure 5-2.5**) and contains carbonate-hosted lead-zinc replacement, volcanic-epithermal, and carbonate-hosted manganese deposits (**table 5-2.5**)(see Sutphin, chapter 2, this volume). Prospecting began in 1880. Production of copper, silver, gold, and lead has been minor, including less than 10,000 lbs Cu and greater than 10,000 oz Ag (**table 1-3**).

District Geology

In the northern Animas Mountains, the oldest rocks are 1,200 Ma (Soulé, 1972; Drewes, 1986) Proterozoic porphyritic, coarse-grained granites that are unconformably overlain by Paleozoic marine and Cretaceous clastic sedimentary rocks. Tertiary post-orogenic intrusive and volcanic rocks are the youngest rocks in the district. One intrusive is 34 Ma quartz monzonite porphyry (K-feldspar, $^{40}Ar/^{39}Ar$; McLemore and others, 1995). Rhyolite dikes occur in the northern part of the district along post-Laramide normal faults or as linear zones (Soulé, 1972). The area is characterized by gravity and magnetic lows that may be related to regional hydrothermal alteration (see Abrams and Klein, chapter 3, this volume). Stream-sediment geochemical anomalies in the area include As, Cd, Cu, La, and Th, and local Nb and Pb (Hassemer and Marsh, unpublished data, 1995).

Mineral Deposits

Rincon Mine is a carbonate-hosted lead-zinc replacement deposit located southeast of a northeast– trending strike-slip fault, and is hosted by Horquilla Limestone. Mineralized limestone beneath gray to black shale is brecciated and folded and 0.5-1.5m thick (Elston, 1960). The main workings are along two fault zones striking N. 45° W. and N. 80° E., and dipping 56° NE and 56° NNW, respectively (Elston, 1960). Jasperoid is common. Ore minerals include galena, chalcopyrite, sphalerite, and hemimorphite.

Fredingbloom, Zinc, and White Rose Mines occur along a ridge underlain by Escabrosa Group limestone. Ore occurs predominantly in replacement deposits in fault zones. Smithsonite

and anglesite are dominant minerals at the Fredingbloom and Zinc Mines, whereas barite, galena, and sphalerite are dominant minerals at the White Rose Mine (Elston, 1960). Chrysocolla is found at the Zinc Mine. A sample from the Zinc Mine assayed 35 percent Pb and 14 percent Zn (Elston, 1960).

Cowboy Mine is in a volcanic-epithermal vein in rhyolite at Red Hill (not to be confused with the Red Hill Mine in the Gillespie district). Several small quartz veins occur in a zone less than one meter wide and a few meters long. Quartz, iron, and manganese oxides with trace amounts of pyrite and gold occur in the veins (Elston, 1960).

Additional carbonate-hosted lead-zinc replacement and volcanic-epithermal vein deposits are found scattered throughout the district, but none have yielded large amounts of ore. These deposits are typically small and similar to those described above. Economic potential appears low for most of the deposits, but they could be indicative of larger deposits in the subsurface.

Small carbonate-hosted manganese deposits occur along faults and fractures within Paleozoic carbonate rocks at the Blacktop No. 1 claim. A grab sample of ore assayed 28.55 percent Mn, 0.27 percent Cu, 0.50 percent Pb, and 0.26 percent Zn (Elston, 1960).

Fire clay has been produced from near the Animas district from the early 1900s to the present. Deposits are formed by hydrothermal alteration of andesite in fault zones. Paleozoic and Cretaceous limestone units are present for potential use as building stone or other uses, but are of insufficient quantity and are too remote to be of economic significance.

BIG HATCHET MOUNTAINS

Big Hatchet Mountains contains the Big Hatchet Mountains district.

Big Hatchet Mountains District

Location, Mining History

Big Hatchet Mountains mining district is in the Big Hatchet Mountains in southern Hidalgo County (**figure 4-2.1**). Prospecting began in the mountains in 1917. Extensive occurrences of gypsum and minor carbonate-hosted lead-zinc-silver replacement deposits are present; production is small (**table 5-2.6**)(see Sutphin, this volume). Mines are located in the Big Hatchet State Game Refuge and the Big Hatchet WSA. Early production records are not available or are ambiguous, but total production from 1920 to 1931 is estimated as less than $2,000 (**table 1-3**; Elston, 1965). In 1917, one carload of zinc ore was shipped from the Sheridan Mine, and in 1919 a small lot was shipped from the Brock Mine (Elston, 1960). Since then, the only known production has been several truck loads of agricultural-grade gypsum (50-70 percent $CaSO_4 \cdot 2H_2O$) that were shipped in the 1950s and 1960s.

District Geology

The Big Hatchet Mountains consist of faulted and tilted Paleozoic limestone and Cretaceous shale and sandstone that show few signs of mineralization or alteration (Lindgren and others, 1910; Drewes, 1991). Rocks in the district consist predominantly of Horquilla Limestone and Earp Formation overlain by Colina Limestone and Oligocene andesite or basaltic–andesite. Thrust faults occur on the west side of the district, where small carbonate-hosted lead-zinc replacement deposits have been identified. The district is associated with large gravity and magnetic lows and a low aeroradiometric K and Th and slightly elevated U aeroradiometric anomaly, which is characteristic of mineralized carbonate rocks in the Mimbres Resource Area (see Abrams and Klein; Pitkin, chapter 3, this volume).

Mineral Deposits

Two types of mineral deposits have been identified in the Big Hatchet Mountains mining district—small carbonate-hosted lead-zinc replacement deposits of presumably Tertiary age, and bedded gypsum deposits in Epitaph Dolomite. Additionally, gypsum occurs in the foothills south of the Big Hatchet Mountains in the Hell-To-Finish Formation. Replacement lead-zinc deposits occur in two areas of the district—at the Sheridan Mine in the northern part of the district, and at the Lead Queen Mine in the southern part (**figure 4-2.1**; **table 5-2.6**). Marine gypsum deposits in the western part of the district have been quarried at the Proverbial Mine.

At Sheridan and Lead Queen Mines, lead-silver-zinc oxide and sulfide minerals occur within calcite and limonite-manganese-stained gouge along bedding planes and faults in Horquilla Limestone (Scott, 1986; Drewes and others, 1988). Smithsonite and galena occur along a fault at the Sheridan Mine. The fault is less than 1.2m wide and was traced for 49m underground. Samples assayed as high as 0.39 percent Cd, 16.6 percent Pb, 1.8 oz/short ton Ag, and 36.1 percent Zn (Scott, 1986; Drewes and others, 1988). Silver is associated with the lead minerals and cadmium is associated with the zinc minerals. The remaining indicated resources at the Sheridan Mine are estimated as 4,500 short tons of material averaging 3.2 percent Pb, 0.4 oz/short ton Ag, and 2.2 percent Zn (Scott, 1986; Drewes and others, 1988). These resources are probably of low grade and small tonnage, and are presently subeconomic.

Lead Queen Mine contains less calcite, more galena, and greater concentrations of cadmium, lead, silver, and zinc than found at the Sheridan Mine (Scott, 1986; Drewes and others, 1988). Samples assayed as high as 0.12 percent Cd, 0.01 percent Cu, 33.2 percent Pb, 7.4 oz/short ton Ag, and 16.9 percent Zn. Three mineralized faults at the mine were estimated to contain a total of 2,900 short tons of material averaging 0.21 percent Pb, 1.1 oz/short ton Ag, and 0.5 percent Zn (Scott, 1986; Drewes and others, 1988). As with the Sheridan Mine, reported low

grade and small tonnage makes the Lead Queen Mine subeconomic. Exploration down-dip and along strike at both the Sheridan and Lead Queen Mines could increase the potential for additional deposits (Drewes and others, 1988). However, the area along Sheridan Canyon fault between Mine Canyon Tank and Hell-To-Get-To Tank was identified as having low mineral potential owing to evidence at the Lead Queen, Sheridan, and other prospects where past exploration has taken place (Drewes and others, 1988).

Additional sites of subeconomic resources were identified in the area east of Sheridan Canyon fault. These sites occur in the vicinity of several calcite veins. Most of these veins are less than one meter thick and are typically barren of metals, but some contain small, localized occurrences of Ag, As, Ba, Cu, and Zn (Drewes and others, 1988). Geochemical anomalies of As, Cd, Sn, and Ti are scattered in stream-sediment samples in the Big Hatchet Mountains, and selected samples contain anomalous concentrations of Co, Mn, Nb, and U at the south end of the range (Hassemer and Marsh, unpublished data, 1995).

At Proverbial quarry, gypsum is at least 9m thick in Epitaph Dolomite within an irregular dome-like structure. The deposit contains gypsum, anhydrite, and such impurities as clay, dolomite, limestone, and shale. Samples from the Proverbial Mine contained 60-80 percent $CaSO_4 \cdot 2H_2O$. Distance to market plays an important role in the economic viability of the low-value, high-tonnage gypsum deposits. Distance to potential markets precludes development of the Proverbial Mine in the Big Hatchet Mountains for the foreseeable future.

Weber and Kottlowski (1959) describe deposits of Permian gypsum exposed at the southwestern edge of the Big Hatchet Mountains, in secs. 20, 21, 28, 29; T.31S., R.15W. The exposure covers about 23 acres and has a thickness estimated between 61m and 92m. The gypsum is highly contorted and interbedded with dolomite. Weber and Kottlowski (1959) suggest that the substantial thickness is due to plastic flow of the gypsum at the base of overthrust sheets.

Weber and Kottlowski (1959) report exposures of gypsum in Lower Cretaceous rocks at two locations in the foothills south of the Big Hatchet Mountains. One locality is in a gully near the center of $NW^1/_4NW^1/_4$ sec. 10, T.32S., R.15W., and the other is in a gully in $NW^1/_4SW^1/_4SW^1/_4$ sec. 3, T.32S., R.15W. At least two beds of gypsum have been identified as interbedded with red shale, red sandstone, and marine limestone in the uppermost Hell-to-Finish Formation and below limestone in the U-Bar Formation. Estimated combined maximum thickness of the two beds is about 18 m, and they have been traced for approximately 0.5 km. The gypsum deposits appear to be of high purity, but are too distant from markets to be of current commercial interest.

Additional industrial commodities include local occurrences of high-calcium limestone in the Escabrosa Group limestone, El Paso Limestone, Horquilla Limestone, Colina Limestone, and Early Cretaceous rocks.

LITTLE HATCHET MOUNTAINS

Little Hatchet Mountains contains the Sylvanite mining district. (See also Eureka district, Little Hatchet Mountains, Grant County.)

Sylvanite District

Location, Mining History

Sylvanite mining district is located south of Eureka mining district in the Little Hatchet Mountains. In some reports (Anderson, 1957; Johnson, 1972), Sylvanite mining district is included with Eureka district to form Hachita mining district. Laramide skarn, Laramide vein, and placer deposits (see Sutphin, chapter 2, this volume) occur in the district and production includes 2,500 oz Au, 130,000 lbs Cu, and 8,000 lbs Pb (**table 5-2.7**). In the southern portion of the district, 650 short tons of scheelite-garnet ore grading 0.44 percent WO_3 was produced from a small skarn (Dale and McKinney, 1959).

The abandoned town of Sylvanite is located about 20 km southwest of Hachita (**figure 5-2.6**). Copper was discovered in several locations in the area in the 1880s (Lindgren and others, 1910). In 1908, a worker at the Wake Up Charlie claims discovered placer gold and tetradymite in a small gulch east of Cottonwood Spring (Lasky, 1947). The tetradymite was misidentified as sylvanite, a gold telluride that the prospector had seen at Cripple Creek. This led to the naming of the Sylvanite mining camp and to a gold rush (Jones, 1908 a,b; Dinsmore, 1908; Martin, 1908).

After discovery, placers were mined by hand using simple techniques and implements. Dry washers and rockers were employed in concentrating the gold owing to the shortage of water (Lindgren and others, 1910). Placers were not extensive, and by March 1908, they had been largely abandoned. Despite early optimism, the value of the placer gold was not great (Anderson, 1957). Total placer production was estimated to be less than 200 oz. The short duration of the gold rush is reflected in the history of the town of Sylvanite, which was established in 1908 and had a population of 500-1,000. By 1909, with abandonment of the placers, the population had dropped to 70. Placer gold can still be found in some of the arroyos (Johnson, 1972; McLemore, 1994b). An earlier-abandoned placer operation in sec. 13, T.28S., R.16W., appears to have been worked recently.

When placer production declined, prospecting for gold-bearing hard-rock deposits began. Most deposits in the Little Hatchet Mountains that had been explored up to 1937 were small. At

that time, all shoots of minable size appeared to have been exhausted to water-table depth. A few of the mines extended just below the water table, and are now flooded.

Ten types of mineral deposits are described (Lasky, 1947); only a few have accounted for past production (Elston, 1965a). Several produced gold and other metals for a significant period. A small amount of scheelite was produced from the Eagle Point tungsten claims in 1943 (650 short tons of 0.44 percent $W0_3$; Dale and McKinney, 1959). The last ore shipment reported was in the early 1950s from Hornet Mine (Anderson, 1957). Copper Dick deposit was discovered in the 1890s and, from 1905 to 1954, produced copper, silver, gold, and lead from underground mining. An attempt to ship ore from an open cut at Copper Dick Mine was not successful.

From the 1960s to 1970s, Exxon Corporation drilled ten holes (greater than 9,150m total); Phelps Dodge, Inc., also examined the area. In 1990, Champion Resources, Inc., drilled 27 holes (total 3,660 m) and in 1991-1993, Challenger Gold formed a joint venture with Champion Resources, drilling 7 additional holes (for a total of 2,135 m). Results were not encouraging, but drilling intercepted 12.2m of rock assaying at 0.06 oz/short ton Au.

District Geology

Proterozoic porphyritic granite has been cut by northeast-trending aplite dikes in the southern Little Hatchet Mountains (Lasky, 1947; Zeller, 1970). Younger rocks in the district include Paleozoic and Mesozoic sedimentary rocks and Tertiary volcanic rocks. Cretaceous sedimentary units make up the bulk of exposures in the Little Hatchet Mountains. The upper part of the volcanic sequence is truncated by a thrust fault. Middle to late Tertiary volcanic rocks rest with angular unconformity on the older rocks.

Several Laramide stocks, dikes, and sills have intruded Cretaceous sedimentary rocks, and the most highly mineralized areas are associated with these intrusions. Quartz monzonite and monzonite in the Sylvanite district is called the Sylvanite quartz monzonite stock (Zeller, 1970); detailed studies are needed to determine if there is more than one intrusive phase. North of Hachita Peak, stocks and large sills of diorite form much of the eastern and northern slopes. Younger intrusives and the granite at Granite Pass [43-48 m.y. (zircon, fission track; Zeller, 1970)] are intruded by rhyolite, felsite, and lamprophyre and latite dikes.

Mineral Deposits

Four deposit types occur in the district: Laramide veins, Laramide skarns, disseminated pyrite in Tertiary intrusive rocks, and gold placers (**table 5-2.8**). Lasky (1947) describes ten different mineralogical associations: (1) disseminated pyrite in Tertiary intrusive rocks, (2) chalcopyrite skarns (Copper Dick Mine), (3) pyrrhotite replacements (Clemmie Mine), (4) chalcopyrite– tourmaline veins (Buckhorn Mine), (5) arsenopyrite-tourmaline veins (Creeper

Mine), (6) tetrahydymite-native gold veins (Gold Hill Mine)(**figure 5-2.7**), (7) chalcopyrite-barite veins (Santa Maria Mine), (8) galena veins (Silver Trail Mine), (9) quartz-pyrite-chalcopyrite veins (Broken Jug Mine), and (10) fluorite-calcite-quartz veins. They are hosted in Cretaceous sedimentary rocks and in Tertiary granitic or mafic intrusive rocks.

Gold in the district occurs mainly in quartz fissure-veins in the Sylvanite stock and adjacent limestone (Anderson, 1957). There is potential for gold-bearing skarn deposits. Veins are typically composed of coarse-grained white quartz that cuts and replaces altered host rocks (Lasky, 1947). Tourmaline occurs in altered rocks; actinolite and chlorite occur in pockets in quartz. Tetradymite may be the most abundant gold-bearing mineral. Veins are typically short, erratic, steeply dipping, lenticular, and less than 4.6m wide. Many occur near lamprophyre dikes. Samples from some of the earliest production reportedly assayed 216-300 oz/short ton Au (Martin, 1908). Lasky (1938b) suggests the potential for similar deposits in the subsurface between the Sylvanite and Eureka districts.

Buckhorn Mine is in metamorphosed limestone beds about 153m north of the Sylvanite stock. An exposed vein in the mine trends S. 70˚ E. and dips 70˚-90˚ NE (Lasky, 1947). The vein averages 1.5-1.8m in width, but varies from 0.3m-4.6m, and lies between a lamprophyre dike and garnetized metasedimentary rocks. In some places, clay gouge and breccia occur along the vein. Native gold, silver, chalcopyrite, sphalerite, bismuthite, and tellurobismuthite are ore minerals; quartz, calcite, tourmaline, limonite, pyrite, and chlorite are gangue.

At Green Mine, gold occurs in a lenticular quartz vein in garnetiferous limestone conglomerate. Dikes and quartz monzonite of the Sylvanite stock are associated igneous rocks. The most abundant metallic ore mineral is tetradymite (Lasky, 1947). Visible gold forms grains and thin streaks in the quartz. Ag/Au ratio at Green Mine is about 1.5-2.0:1.0; most of the silver is in hessite. Chemical analyses of selected samples from Sylvanite mining district are shown in **table 5-2.9**).

Eagle Point, Cactus Group, and Copper Dick Mines are skarn deposits. A small tungsten skarn occurs in a garnetiferous zone along the contact between Horquilla Limestone and Tertiary intrusive rocks at Eagle Point claims at the southern tip of the area (**figure 5-2.8A**; Dale and McKinney, 1959). Molybdenum is present, and garnet is a gangue mineral. Contacts between tungsten-copper-lead skarns and limestone are irregular, but sharp (**figure 5-2.8B**). Another small molybdenum–tungsten–bearing skarn occurs in a garnetiferous zone in the Howells Ridge Formation at Cactus Group claims (Dale and McKinney, 1959; Hammarstrom and others, 1988). Scheelite was the mineral of interest at these deposits.

Copper Dick Mine, at the intersection with a lamprophyre dike in Hell-to-Finish Formation limestone, is a copper-garnet skarn deposit. Calc-silicate skarn minerals, including epidote, chlorite, and actinolite, are present as gangue minerals. A small bismuth anomaly was discovered by Challenger Resources in the southern part of the district that may be related to lead-zinc and(or) gold skarns.

Near Cottonwood Spring, zones of disseminated pyrite occur in the monzonite, which is altered to jarosite, iron oxides, and pyrite. Unaltered, pre-ore lamprophyre dikes cut the altered monzonite, suggesting that the alteration may be older than mineralization (Lasky, 1947).

Gold placer deposits are found in many of the arroyos draining the lode deposits. Panning of most arroyos yields free gold. However, none of the placer deposits are sufficiently large to be economic.

PELONCILLO MOUNTAINS

Peloncillo Mountains contains the Granite Gap, Kimball, McGhee Peak, and Silver Tip mining districts.

Granite Gap District

Location, Mining History

Granite Gap (San Simon) mining district is at the southern end of the central Peloncillo Mountains, north of Granite Gap WSA, east of the Ariz.-N.Mex.stateline, and southwest of Lordsburg (**figure 1-12**). Two deposit types occur in the district: carbonate-hosted lead-zinc replacement deposits and Laramide skarn deposits. Mines south of Blue Mountain and along Granite Gap are included in the district.

Deposits in the district were first explored in about 1887, but large-scale mining operations did not begin until 1897 when control of several Granite Gap Mine properties were consolidated (Gillerman, 1958). Most production ended in 1915, but small amounts of ore were produced sporadically until 1926 and possibly until the 1950s. Most lead and silver ore was shipped to Douglas, Ariz., El Paso, Tex., and Deming. Crystal Mine was in operation in 1954-1955, but total production is not known. Total estimated production from the district includes more than 1.6 million lbs Pb and 91,000 oz Ag (**table 5-2.10**). In addition, 300 short tons of 0.5 percent WO_3 were produced in 1943, and in 1948, 5 short tons of 6 percent Sb was produced (Hobbs, 1965; Dasch, 1965).

District Geology

The oldest rocks (Proterozoic granite) crop out in a northwest-trending band north of Preacher Mountain in the northern part of the district. The rest of the district is underlain mainly by Cretaceous and Paleozoic sedimentary rocks that are exposed in fault-bounded blocks. An area in

the southern part of the district near Granite Gap has been intruded by Granite Gap granite (Cargo, 1959; Armstrong and others, 1978; Gebben, 1978; Drewes and Thorman, 1980; Richter and others, 1990). The granite is located mainly between the Preacher Mountain and Granite Gap faults. Gillerman (1958) described the granite as Proterozoic, and part of a fault-bounded horst transversing ENE across the central mountain range at Granite Gap. However, $^{40}Ar/^{39}Ar$ age determination of the Granite Gap pluton indicates emplacement near 33 Ma (McLemore and others, 1995). Several dikes, sills, and irregular masses of Tertiary granite porphyry intrude both the Granite Gap granite and Cretaceous and Paleozoic rocks in the central Peloncillo Mountains (**figure 5-2.9**). The area is characterized by magnetic and gravity highs and high resistivity, which is consistent with the presence of some plutons (see Abrams and Klein; Klein; chapter 3, this volume).

Mineral Deposits

Skarn and carbonate-hosted lead-zinc replacement deposits (see Sutphin, chapter 2, this volume) in the Granite Gap mining district are associated with Tertiary intrusions. Skarn mineralization in the Granite Gap mining district is less well developed than at the McGhee Peak district to the north. Deposits with similar mineralogy in limestone occur in two geographic areas adjacent to Tertiary igneous intrusive rocks --those along the Preacher Mountain fault bounding the northern limit of the Granite Gap granite (Crystal Mine), and those near the Granite Gap fault. Vein deposits in the district are fissure fillings, mostly within limestone, such as those at the Granite Gap and Crystal mines. Skarns in the Granite Gap district have replaced limestone with calc-silicate minerals (mainly garnet with minor quartz, calcite, epidote, and wollastonite); some zones contain 60 percent andradite garnet (Cargo, 1959). Skarn mineralization was accompanied by introduction of galena, sphalerite, and chalcopyrite (Armstrong and others, 1978). Tungsten is present in several mines (**table 5-2.11**; Dale and McKinney, 1959).

Primary ore minerals are sphalerite, galena, and chalcopyrite with minor tetrahedrite in a gangue of quartz, calcite, pyrrhotite, barite, and pyrite. Silver occurs as matildite blebs in galena; assays of 100-500 oz/short ton Ag are common (Williams, 1978). Bismuth occurs in arsenopyrite (Williams, 1978); scheelite and molybdenite are present in some mines. At Granite Gap, sulfides have been nearly oxidized to limonite and manganese oxides. Jasperoids are common. It is likely, then, that these skarn deposits developed near intrusive bodies, the main sources of heat and possibly metals. Carbonate-hosted lead-zinc replacement deposits formed at lower temperatures further from the intrusives (McLemore and Lueth, 1995). Regional geochemical anomalies of Be, Mo, Nb, Pb, Th, and U and localized anomalies of Ag, La, and Sn are found in stream-sediment samples from the area (Hassemer and Marsh, unpublished data, 1995).

Tungsten occurs with base- and precious-metals in some mines, especially along the Preacher Mountain fault (Cargo, 1959). At Sunrise Mine, scheelite with molybdenum occurs in quartz veins in granite and as disseminations in the garnet zone along the contact. Assays as high as 0.58 percent WO_3 are reported (Dale and McKinney, 1959). Scheelite occurs in small pods and zones as much as 1.8m wide in tactite at the Baker-Standard claims. Assays as high as 1.2 percent WO_3 are reported from the Buck Deer claims (Dale and McKinney, 1959).

Kimball District

Location, Mining History

Kimball (Steins Pass) mining district is in the northern Peloncillo Mountains at the Ariz-N.Mex. stateline and north of the McGhee Peak mining district (**figure 1-12**). This district includes mines and prospects north of Steins Pass, as well as those in secs. 16, 17, 20, 21, T.24S., R.21W. (Elston, 1960). Elston (1960) places the Charles Mine in the McGhee Peak district; however, since it is a volcanic-epithermal vein deposit similar to other mines in the Kimball district, it is included in the Kimball district herein.

Volcanic-epithermal vein deposits were discovered in the area in 1875, but mining did not begin until about 1883 (Wells and Wootton, 1932, 1940). Production from 1885 to 1933 included 400,000 oz Ag, 1,500 oz Au, 125,000 lbs Pb, and 12,000 lbs Cu (**table 1-3**). Most production took place prior to 1910, but development continued until about 1981. Silver is the main product, but a considerable amount of gold was also produced. Volcano silver mine and Beck gold mine were the main producers (**table 5-2.12**). Some manganese was produced from the Black Face Mine during World War II (Farnham, 1961).

Volcano Mine was the largest mine in the district, having produced significant amounts of silver ore before 1905, and shipping more than 4,000 short tons between 1909 and 1947 (Richter and Lawrence, 1983). Beck Mine operated intermittently until 1936, producing considerable, but unknown, amounts of gold-silver ore. In 1980, the Beck property was under development for cyanide leaching (Enders, 1981).

District Geology

The district is located in an area of rhyolite domes and flows that occur north and west of the district and on an elongate gravity high and a magnetic low, which may represent regional alteration (Abrams and Klein, chapter 3, this volume). Rocks in the district are volcanic and igneous intrusive rocks, including rhyolite domes and flows, tuffs, and megabreccias. Much of the district is underlain by the Steins tuff, a light colored, densely welded ash-flow tuff that was defined by Richter and others (1990) as being related to the Steins caldera. Lindgren and others (1910) describe the rocks as being similar to those in the Steeple Rock district to the north. Some

faults are present, and mineralized epithermal quartz veins are identified in silicified, brecciated fault zones within igneous rocks.

Mineral Deposits

Volcanic-epithermal veins occur in late Cretaceous or Tertiary volcanic rocks and consist of pyrite, chalcopyrite, galena, sphalerite, argentite, cerargyrite, and native gold (Lindgren and others, 1910; Lasky and Wootton, 1933; Elston, 1960). Most of the veins are oxidized, but some sulfides are present. Calcite is prevalent, especially near the surface. Stream-sediment geochemical anomalies include Ag, Cu, Pb, Sn, and spotty La and Mn (Hassemer and Marsh, unpublished data, 1995).

Volcano and Beck Mines are the largest mines in the district. Volcano Mine sits atop the 2,745 m-long, northeast-trending Volcano vein, which reaches a width of as much as 14 m. The vein is brecciated, fissure-filling, and silicified, and forms a prominent exposure. Ore existed in a quartz band on the hanging-wall side of the brecciated zone. Cerargyrite was the main ore mineral in the oxidized zone.

Beck Mine is situated within the west-northwest-trending Beck vein, which extends for 915m in middle Tertiary andesitic rocks that have been cut by prominent dikes of monzonite porphyry (Enders, 1981; Richter and Lawrence, 1983). Argillic alteration is prevalent. Ore minerals include cerargyrite, argentite, pyrargyrite, proustite, sphalerite, galena, chalcopyrite, bornite, with chalcocite, with calcite, pyrite, clay, and quartz as gangue (Enders, 1981; Lindgren and others, 1910). Samples assayed as high as 1.05 oz/short ton Au, 25.11 oz/short ton Ag, 2.06 percent Cu, 0.33 percent Pb, 0.12 percent Zn, less than 300 ppb As, less than 10 ppm Sb, and less than 300 ppb Hg (Enders, 1981). Most assays were lower. Metal concentrations are higher in the upper levels of the mines, especially at the Beck Mine. According to Enders (1981), the most favorable areas for future exploration are the eastern extension of the Beck vein and the Ester Mine area.

Epithermal manganese veins occur in rhyolite porphyry at the Black Face Mine in the northern part of the district (Farnham, 1961). The veins are up to 214m long, strike N. 70° E., and dip from 75° N. to vertical.

McGhee Peak District

Location, Mining History

McGhee Peak mining district is located in the central Peloncillo Mountains north of Granite Gap and contains the abandoned mining camp of McGheeville (**figure 5-2.10**). Mineralized skarns were first identified in the district in 1894, but it was not until 1904 that the McGhee family

acquired the mining rights to the area (Don McGhee, mine owner, spoken communication, 4/18/94). Carbonate-hosted lead-zinc replacement and Laramide skarn deposits were mined, yielding 12 million lbs Pb, 10 million lbs Zn, 85,000 lbs Cu, 100 oz Au, and 200,000 oz Ag. The district contains only trace amounts of gold. McGhee Peak mining district leads the county in lead and zinc production. Recent drilling has determined that a porphyry copper deposit occurs in the subsurface in the northwestern part of the district.

Until June 1948, the Carbonate Hill (McGhee) Mine was the largest and most productive in the district. That year, fire destroyed the head frame, shaft timbers, and surface buildings (Anderson, 1957). Total production from the mine was probably greater than $1.5 million (Gillerman, 1958). About 91 percent of reported value of production was from lead and zinc and 9 percent was from silver. The most recent production was in 1956, when about 100,000 short tons averaging 6 percent Pb, 5.0-6.5 percent Zn, and 1-2 oz/short ton Ag were produced (Gillerman, 1958; Richter and Lawrence, 1983; Don McGhee, mine owner, spoken communication, 4/18/94).

District Geology

The central Peloncillo Mountains consist of a faulted arch of Proterzoic to middle Tertiary age, with a sequence of extrusive, intrusive, and sedimentary rocks. The sedimentary rocks include Paleozoic carbonate rocks and Mesozoic clastic rocks containing carbonate units. This sequence is overlain by middle Tertiary and younger extrusive rocks (Armstrong and others, 1978), and the sedimentary rocks and Precambrian granite are intruded and metamorphosed by a several igneous units. South of the district at Granite Gap, 33 Ma Tertiary granite was emplaced (McLemore and others, 1995). Granite porphyry dikes and sills were intruded at 30-33 Ma (biotite, K-feldspar, K-Ar; Hoggatt and others, 1977). Intrusion of fine-grained porphyritic to felsic rhyolite dikes (probably related to the granite porphyry) was followed by intrusion of 26-27 Ma quartz-latite porphyry dikes and sills (biotite, plagioclase, K-Ar; Hoggatt and others, 1977). Dikes and sills of porphyritic granite, rhyolite, and quartz latite over tens of meters thick and up to 915m long are present. Although the dikes and sills vary somewhat in composition and texture, they are quite silicic. The district lies on an elongate gravity high that is consistent with the trend of the intrusive rocks (see Abrams and Klein, chapter 3, this volume). Stream-sediment samples indicate geochemical anomalies of Ba, Co, Cu, Mn, Mo, and Pb, and locally anomalous Be, Bi, and Cr (Hassemer and Marsh, unpublished data, 1995).

Mineral Deposits

Many small, lead-zinc-copper-silver deposits occur in carbonate rocks adjacent to dikes and sills, particularly on the northeast limb of the major anticlinal structure of the mountain range

(**table 5-2.13**). Deposits proximal to intrusive rocks tend to be characterized by skarns with calc-silicate gangue mineralogy, while more distal deposits tend to be more stratigraphically and structurally controlled and are more typical of carbonate-hosted replacement deposits.

At Carbonate Hill Mine, ore at the collar of the shaft contains skarn minerals (epidote, garnet, and wollastonite). However, most of the ore consists of sulfide minerals that replace permeable beds, particularly fossiliferous zones in Horquilla Limestone. Sulfide minerals include galena, cerussite, argentiferous galena, sphalerite, smithsonite, and chalcopyrite. Gangue minerals are quartz, calcite, and garnet. Ore grade was approximately 6 percent Pb, 5 percent Zn, and 68.6 grams/short ton Ag. Workings consist of a main shaft containing about 732m of drifts, a short adit, and several shallow shafts and pits. The main shaft reached a depth of about 183 m, but the working levels were at lesser depths.

Johnny Bull Mine, located about 2 km southwest of the Carbonate Hill Mine, was described by Gillerman (1958) as having produced considerable copper ore prior to 1910. Johnny Bull Mine was probably one of the largest in the area at that time; it is located in copper skarn in Horquilla Limestone adjacent to the northwest-trending Johnny Bull fault. The deposit is in a zone near the contact between limestone and a granite porphyry sill (about 30m west of the sill) and is more copper-rich than the Carbonate Hill deposit. Chalcopyrite, azurite, malachite, galena, bornite, and chrysocolla are the ore minerals; gangue is garnet, calcite, quartz, pyroxene, epidote, and wollastonite. The mine consists of two inclined shafts, with the deeper shaft reaching a depth of 46 m. Johnny Bull Mine was reclaimed by 1958.

Drilling in the early 1970s and 1990s located a porphyry copper deposit in sec. 30, 31, T.24S., R.21W. at a depth of 31 m(unpublished data, NMBMMR). The area of the deposit is now (1996) claimed by Cyprus Minerals Corporation. Most drill holes encountered pyritic and argillic alteration.

Silver Tip District

Location, Mining History

Silver Tip mining district is located in the southern Peloncillo Mountains and straddles the Ariz.-N.Mex. state line (**figure 5-2.11**). The district is named for the Silver Tip Mine, a volcanic-epithermal vein deposit (see Sutphin, chapter 2, this volume), which is located in Arizona about 0.3 mi west of the stateline (sec. 25, T.22S., R.32E., Arizona baseline). The mine consists of a 73-m adit and a 9-m shaft (Hayes and others, 1983); it may have produced, but amounts are not known. There is no production from the New Mexico part of the district. Additional prospects occur along the Silver Tip vein. In the early 1980s, approximately 90 mining claims were filed, mostly near the Silver Tip Mine, and in 1980, geophysical exploration was conducted near the

district. In the mid 1980s, a drilling program was conducted by Nicor Industries, Inc.; no reserves were found. Rhyolite tuff was quarried for local use as building stone north of the district.

District Geology

The district lies within the 24 Ma Geronimo Trail caldera (Deal and others, 1978), which is characterized by a gravity gradient and magnetic high (see Abrams and Klein, chapter 3, this volume). The caldera margin is delineated by an aeroradiometric Th and U high (see Pitkin, chapter 3, this volume).

Oligocene and younger volcanic rocks, which Deal and others (1978) and Erb (1979) suggest were vented from a nearby volcanic center, comprise the district. Rock types include rhyolitic ash-flow tuff, breccias, and dacitic lava. The oldest rhyolite tuffs are 27 Ma (zircon, fission track method; Hayes, 1982). Rhyolite dikes and domes are common in the area (Emanuel, 1985; McIntyre, 1988). Dacitic lavas originated from Oligocene porphyritic flows and domes. Tuffaceous sandstone and conglomerate with interlayered tuff of probable Miocene age occurs in the northern part of the district. Small remnants of Pleistocene or Pliocene olivine basalt cap some hills (Hayes, 1982; Hayes and Brown, 1984). Parallel north-trending normal faults with little displacement cut the volcanic rocks. A structure, interpreted as the Clanton Draw caldera (McIntyre, 1988), truncates Geronimo Trail caldera. Initial collapse of this younger caldera is marked by Skeleton Canyon tuff.

Mineral Deposits

Silver Tip Mine and several nearby prospects are in an area of argillic, advanced-argillic, and silica alteration occurring along fault zones extending for about 0.8 km into New Mexico (Emanuel, 1985; McIntyre, 1988). The deposit is in a 0.3-3.0 m-thick, 458 m-long mineralized fault zone in the ring-fracture of the Geronimo Trail caldera. Pyrite is common and bromargyrite has been identified at the Silver Tip Mine (Emanuel, 1985). Geochemical analyses of rock chip samples collected by Nicor Industries, Inc. show low values, containing as high as 0.62 ppm Au, 8.5 ppm Ag, 225 ppm Cu, 490 ppm Pb, 1350 ppm Zn, and 235 ppm Mo (Emanuel, 1985).

There is little other field evidence of metallic mineralization in the district, but pyrite is locally abundant. Previous studies of the area (mineral-resource surveys of the Bunk Robinson Peak and Whitmire Canyon Roadless Areas of Arizona and New Mexico; Hayes, 1982; Hayes and others, 1983; Watts and others, 1983; Hayes and Brown, 1984) identify a zone of altered rocks having probable mineral potential for Ag, Au, Bi, Mo, Pb, and Zn. The zone, extending about 2.5 km south and southwest from the southern contact of a dacitic lava flow in the northern part of the district, consists of argillic-altered rocks and anomalous As, Ba, Mo, and Pb in stream-sediment samples (Watts and others, 1983). The zone strikes N. 10° W.-N. 15° E.; veins are up to 6m

thick, and are steeply dipping (McIntyre, 1988). Many mining claims are located along this zone.

Northwest and east of the district, Hayes and others (1983) discuss a tract of rhyolitic lava having anomalously high values of Be, Bi, Mo, and Sn in stream-sediment samples. These anomalies may suggest mineralization at depth. Other geochemical samples include anomalous Be, Cu, La, Mo, Pb, and Zn, and local Bi, Co, Nb, Th, U, and Y (Hassemer and Marsh, unpublished data, 1995).

According to Kottlowski (1962), high-calcium limestone may occur locally in the Escabrosa Limestone, Horquilla Limestone, Colina Limestone, and Carbonate Hill Limestone, although they may contain impurities such as chert. Extent of high-calcium limestone in this area is not known.

PLAYAS VALLEY

Brockman mining district is in the Playas Valley.

Brockman District

Brockman district (sec. 12, T.26S., R.17W.) consists of the Brockman silica quarry, operated by Phelps Dodge Corporation, near Playas in southern Hidalgo County. Silica sand has been produced from the Mojado Formation (Cretaceous) since the early 1900s for use as flux in nearby smelters. Less than one million dollars have been produced since the early 1900s. Capacity is approximately 70,000 short tons/year (Austin and others, 1982).

PYRAMID MOUNTAINS

Pyramid Mountains contains the Lordsburg and Muir mining districts.

Lordsburg District

Location, Mining History

Lordsburg mining district (also known as Virginia, Pyramid, Ralston, and Shakespeare) is located in the northern Pyramid Mountains southwest of Lordsburg (**figure 5-2.12**). The first mining locations were made in the district in 1870, along with some early attempts to ship silver ore from the Laramide vein deposits. When the Southern Pacific Railroad reached Lordsburg in 1880, mining began in earnest (Huntington, 1947). Between 1904 and 1933, the Lordsburg area produced more than 1.5 million short tons of copper, gold, silver, and lead ore (**table 5-2.14**; Lasky, 1938a). Huntington (1947) reports that the ore produced between 1904 and 1935 contained 2.58 percent Cu, 0.117 oz/short ton Au, and 2.24 oz/short ton Ag. In addition, a few hundred short tons of fluorite were produced from two veins (Thorman and Drewes, 1978). Total production includes 11 million lbs Pb and 4.2 million lbs Zn. Reported production from the district accounts for more than 96 percent of total production value reported for Hidalgo County

from 1880 to 1978. The district remains active for small, intermittent, silica-flux mining operations. Placer gold has also been reported (Johnson, 1972; McLemore, 1994b).

Two principal producing mines in the district, the Eighty-five and Bonney Mines, are located on northeast-trending faults. They have been mined over a strike length of 1,327m and a depth of about 610m (Clark, 1962, 1970). Eighty-five Mine was the most productive mine in the area; this group of claims produced 90 percent of the ore from 1904 to 1935. Production, however, was dependent on the local copper smelters' need for silica flux ore necessary to reduce the melting point of the copper ore. Miners were paid for the gold and copper content in the flux ore, and penalized for zinc. In 1931, demand ended and mining was suspended. Ore at the Eighty-five Mine came from the Emerald vein, which was mined for a horizontal distance of about 610m and a vertical depth of 580 m, producing about 1.4 million short tons of ore (**figure 5-2.13**). Average ore from this deposit contained 2.8 percent Cu, 1.23 oz/short ton Ag, and 0.111 oz/short ton Au (Lasky, 1938).

Bonney vein was probably the second largest producing vein in the district. Between 1910 and 1940, the Atwood group of claims (including Atwood and Henry Clay Mines) produced 36,630 short tons of ore containing 3,330 oz Au, 136,364 oz Ag, 706 short tons Cu, and about 115 short tons Pb (Huntington, 1947) (**figure 5-2.14**). By 1943, Bonney Mine had been developed for 610m along strike to a vertical depth of 442 m. Minimum width of the stopes was 1.2m and the maximum vein width was about 6.1m (Huntington, 1947). At that time, Bonney Mine was the principal producing mine in the district, having maintained an annual production rate of 3,000 short tons per year for several years (Huntington, 1947).

In 1953 and 1954, perlite was mined from three quarries in the southern part of the district (see Barker and Scharkan, this volume).

District Geology

Host rocks in the district consist of rhyolite breccia, plugs, and Lower Cretaceous flows. Lower Cretaceous flows, which range in composition from andesite to basalt, are at least 610m thick and are intruded by basalt plugs, rhyolite plugs, and rhyolite breccia. Volcanic rocks have been intruded by an irregular, horseshoe-shaped Laramide granodiorite porphyry stock (60 Ma, hornblende, K-Ar; Marvin and others, 1988)(Lasky, 1938a; Thorman and Drewes, 1978b; Elston and others, 1979), and related granodiorite porphyry and(or) aplite dikes. Plugs and dikes of quartz latite and dikes of white felsite cut the granodiorite. The volcanic rocks correspond to large gravity and magnetic highs (see Abrams and Klein, this volume).

Five sets of faults occur in the area: northwest-, north-, northeast-, east-northeast-, and east-trending faults. They generally have vertical dips and are mostly pre-mineralization faults that

acted as channels for later ore-forming solutions (Lasky, 1938a; Clark, 1962, 1970; Jones, 1907). Veins typically show argillic and propylitic alteration (Clark, 1962; Agezo and Norman, 1994).

Mineral Deposits

Deposits in the district are Laramide base- and precious-metal fissure-filling veins in fault and fracture zones that transect the contact zone of the granodiorite porphyry pluton (**table 5-2.15**; **figure 5-2.15**; Wells, 1909; Clark, 1962, 1970; Richter and Lawrence, 1983). Granodiorite and basalt appear to be the most favorable host rocks. Vein deposits, genetically related to the emplacement of the pluton, consist of quartz, pyrite, and lesser amounts of base-metal sulfides, mainly chalcopyrite, galena, and sphalerite. Fluid inclusion studies indicate that the veins were deposited from acidic fluids (pH 4.5-6.0; Agezo and Norman, 1994) at temperatures of 200˚C to more than 300˚C. Gold assays from prospect pits range as high as 3,100 ppb Au (Griswold and others, 1989). Geochemical anomalies from stream-sediment samples in the area are anomalous in Ag, Co, Cr, Cu, Mn, Mo, and Pb, with local anomalies of Ba, Be, K, Nb, Sn, Th, and Y (Hassemer and Marsh, unpublished data, 1995).

At least 7 stages of fault movement and 6 stages of mineralization took place (Lasky, 1938). Vein filling occurred along with faulting and each reopening of the vein system is recognized by a change in character of mineralization. Only the second stage of mineralization yielded economic deposits. Ore minerals include chalcopyrite, galena, and sphalerite in a gangue of tourmaline, calcite, specularite, barite, sericite, manganosiderite, and fluorite. Oxidation and secondary enrichment occurred at variable depths (Lasky, 1936). In some places, sulfides were found near the surface. Oxidation and leaching were seen at the 430-m level in the Eighty-five Mine (Huntington, 1947).

Ore at the Eight-five Mine was found chiefly within or in contact with granodiorite, while at the Bonney, Henry Clay, Atwood, and numerous others mines, the ore is in basalt (Lasky, 1938; Clark, 1970). Bonney vein strikes N. 50˚ E. for more than 915m on the surface, dips steeply NW, and is located about 305m from the granodiorite contact. At depth, the vein is nearly vertical. It averages 1.5-1.8m in width, but may reach a width of as much as 9 m. The vein reportedly contained about 2.6 percent Cu. Drilling showed that the amount of gold and silver decreased rapidly with depth and that the amount of silica gangue decreased from 75 percent in the upper levels to 45 percent at the 458m level.

North of Lordsburg mining district, approximately 16 km NNW of Lordsburg, Raines and others (1985) used Landsat imagery to identify a large, anomalous, limonite area in Cenozoic gravel. With additional geochemical and geophysical data, the area was interpreted as a chemical trap, similar to calcrete uranium deposits that may contain concentrations of uranium. Raines and

others thought that groundwater draining from the Burro Mountains, the site of some uranium deposits, is forced near the surface by a buried bedrock ridge along the western side of the anomaly. Changes in groundwater chemistry may cause precipitation of uranium along the eastern margin of the anomaly.

Fluorite occurs in veins in the southern part of the district (Williams, 1966; McAnulty, 1978)(**figure 5-2.16 A, figure 5-2.16 B**). The deposits are lenticular, occur in a zone about 1-2 km long, are less than 1.2m wide, and contain of fluorite, calcite, and quartz. Ore that was produced averaged 60 percent CaF_2 (Williams, 1966). Fluorite from sec. 2, T.24S., R.19W. had fluid inclusion homogenization temperatures of 142˚C-174˚C and salinities of less than 1.4 equivalent weight percent NaCl; boiling of ore fluids probably did not occur (Elston and others, 1983; Hill, 1994).

Commercial deposits of perlite occur in the southern part of the Lordsburg mining district (see Barker and Scharkan, chapter 7, this volume). Perlite crops out in a northwest-trending band nearly 5 km long and as much as 0.8 km wide (Flege, 1959), where it is typically greenish to dark reddish brown with resinous luster. The perlite is banded and cut by stoney rhyolite, which lessens its value. At Leintendorf Hills perlite mine, perlite occurs in an exposed area of about 2.6 km^2. It forms irregular lenses and seams of devitrified glass and alteration products within a volcanic dome of sodic rhyolite. Perlite deposits are uneconomic owing to the presence of stoney rhyolite; resources were estimated by Flege (1959) to be about 7,650 m^3 (30 million $yd^{3)}$.

Muir District

Location, Mining History

Muir mining district is located in the southern Pyramid Mountains between Lordsburg and Rincon districts; mines and prospects previously have been included in both districts by other workers. Occurrences in the district are mostly fluorite- and volcanic-epithermal vein deposits. Fire clay also occurs in the area.

Past production and known resources in the Muir mining district are generally small, but the district has not been extensively explored. Silver ore has been produced from the Silver Tree Mine, and fluorite has been produced from the Doubtful Mine (**table 5-2.16.**), including 9,175 short tons of fluorspar ore containing about 60 percent CaF_2 between 1942 and 1953.

District Geology

The district is aligned mostly along the northern interior wall of Muir caldera, a deeply eroded caldera filled with Oligocene tuff (Deal and others, 1978; Bartsch-Winkler, chapter 4, this volume). Its westernmost part is within the Lightning Dock Known Geothermal Resources Area

(KGRA) where hot wells (70˚C-115˚C) supply greenhouses with hot water and heat (see Duffield and Priest, this volume). The district lies on both gravity and magnetic highs; the magnetic high is probably caused by a felsic intrusion into the caldera and/or skarn mineralization (see Abrams and Klein, chapter 3, this volume).

In the Pyramid Mountains, hydrothermal alteration took place in Oligocene time during collapse of the Muir caldera, and was repeated during Miocene and later time via hot springs and shallow vein-forming hydrothermal fluids (Elston and others, 1983). Oligocene alteration is widespread, but is unrelated to present thermal activity. José Placencia Canyon rhyolite and Woodhaul Canyon tuff are intensely argillized; pyrite is widespread (Elston and others, 1983). Modern geothermal activity may be a relict of widespread, fault-controlled hot-spring activity over the last 20 m.y. Fluorine-bearing waters of the Lightning Dock KGRA may be a late-stage product of the hydrothermal activity.

Mineral Deposits

Veins of several ages and mineral assemblages occur scattered throughout the district. The veins are fault- and fracture-controlled in the ring-fracture zone of the Muir caldera, and are associated with argillic alteration characterized by chlorite, pyrite, and quartz. Fluorite was found in drill cuttings at the Cockrell Corp. No. 1 Federal well in sec. 21, T.24S., R.19W. (Elston and others, 1983). Stream-sediment geochemical anomalies include Ag, Ba, Be, Co, Mo, Pb, Y, and Zn, localized Cd and Nb, K to the west, and Cr and U in the northwest (Hassemer and Marsh, unpublished data, 1995).

Fluorspar deposits at the Doubtful (Animas) vein are unrelated to the adjacent porphyry (Elston, 1994). The deposit occurs in a fissure vein that strikes N. 20˚ W. and dips 80˚ SW in fine-grained andesite that is interpreted to be 36 Ma (Elston, 1994). Green and white, fine-grained to coarsely crystalline fluorite is interwoven with finely crystalline white quartz, manganese oxides, and manganiferous calcite. The fluorite material fills a series of nearly vertical veinlets and cements breccia along the vein. Average vein thickness is 1.2 m, with a maximum thickness of 3m. A grab sample of stockpiled material contained 43.0 percent CaF_2, 28.6 percent SiO_2, and 19.5 percent $CaCO_3$ (Williams, 1966). Age of mineralization is most likely Miocene or younger (Elston and others, 1983).

Volcanic-epithermal veins at the Silver Tree and Allen Mines are in Holtkamp Canyon andesite and Woodhaul Canyon tuff (Elston and others, 1983). Veins consist of pyrite, quartz, galena, and stibnite. Additional volcanic-epithermal veins occur in the area.

SIERRA RICA/APACHE HILLS

Sierra Rica/Apache Hills contains the Apache No. 2 and Fremont mining districts.

Apache No. 2 District

Location, Mining History

Apache No. 2 (Anderson, Hachita) mining district, discovered in the late 1870s, is located in the Apache Hills in easternmost Hidalgo County (**figure 5-2.17**). Copper, silver, lead, gold, and zinc were produced from the Apache No. 2 district from 1880 to 1956, including 1.3 million lbs Cu and 300,000 lbs Pb (**table 5-2.17**; Elston, 1965). Chief products of the district have been copper ore containing gold and silver; considerable amounts of scheelite are also present (Lasky and Wootton, 1933). Bismuth was recovered from some ore, and silver ore was shipped (Lasky and Wootton, 1933).

Three major mines, the Apache, Chapo, and Daisy, are located in the district (**table 5-2.18**). Apache Mine was first operated by the Chihuahua Indians, who carted ore to Chihuahua for smelting (Strongin, 1958). Robert Anderson operated the mine for several years starting in 1880. Most mining took place in 1900-1908.

In the early days, rich silver ore consisted mainly of cerargyrite, but later, oxidized copper ore was shipped that contained as much as 4 percent Cu, 0.04 oz/short ton Au, and 6 oz/short ton Ag. Ore was rich in calcite, and was in demand as a smelter flux. In 1915-1919, large quantities of silver-copper ore with bismuth in calcite gangue were mined. In 1927-1929, a considerable tonnage of ore averaging 1.5 percent Cu and 1.5 oz/short ton Ag was shipped, as well as several carloads of ore averaging 12 oz/short ton Ag and 10 percent Pb. Since that time, only small amounts of ore have been taken from the Apache Mine. At Daisy Mine, the last known operation was in 1908, when ore assaying 18 percent Cu, 18 oz/short ton Ag, and 0.03-0.14 oz/short ton Au was shipped. Total production from the Daisy Mine is estimated to be less than $10,000 (Strongin, 1958). At Chapo Mine, the only production data available indicates that some unknown amount of copper-gold ore was shipped in 1940 (Strongin, 1958).

District Geology

Apache Hills consist of Tertiary volcanic rocks overlying Cretaceous sedimentary rocks and Paleozoic limestone (Strongin, 1958; Peterson, 1976). Volcanic rocks (mainly 33 Ma Chapo Formation (K-feldspar, K-Ar; Deal and others, 1978) are intruded by the 27 Ma Apache quartz monzonite porphyry stock (K-Ar, feldspar; Peterson, 1976; Deal and others, 1978). Irregular dikes and sills of monzonite porphyry are present in the Cretaceous rocks, and propylitic and silicic alteration is pervasive. The district lies within gravity and magnetic highs that form a geophysical trend that includes the Fremont district to the south (see Abrams and Klein, chapter 3, this

volume). The area coincides with a low aeroradiometric K and Th and slightly elevated U aeroradiometric anomaly, which is characteristic of mineralized carbonate rocks in the Mimbres Resource Area (see Pitkin, chapter 3, this volume).

Mineral Deposits

Three types of deposits occur in the district: skarns, carbonate-hosted lead-zinc replacement, and polymetallic-vein deposits. Oxidized skarn and carbonate-hosted lead-zinc replacement deposits with associated copper sulfides occur where limestone of the U-Bar Formation is in contact with quartz monzonite. The deposits extend into Mexico. Additional copper replacement deposits are associated with monzonite and rhyolite dikes that may be part of a resurgent magma within Apache caldera (Elston and others, 1979; Deal and others, 1978). Mineralization occurred after emplacement of a massive dike of xenolith-rich rhyolite porphyry along the Apache fault. Apache fault extends along the southwestern margin of the resurgent quartz monzonite stock (Elston, 1983). A thin, but persistent, zone of oxidized copper replacement deposits extend along the contact between the dike and Cretaceous limestone. The rhyolite is younger than, but is probably related to, Apache Hills quartz monzonite stock. Predominant ore minerals include malachite, azurite, and chrysocolla. An ore shipment in 1914 assayed 1.55 percent Cu and 2 oz/short ton Ag (Wade, 1914).

Apache ore body is an irregularly shaped skarn deposit at the contact between quartz monzonite porphyry and Cretaceous limestone (Lindgren and others, 1910). Ore deposition was apparently controlled by major structures having a northerly trend, the most prominent being the McKinley fault, which hosts the Apache deposit on its southeast side (**figure 5-2.17**). McKinley fault is only slightly mineralized, however, with galena, sphalerite, and chalcopyrite forming primary mineralization. Zones of skarn in limestone follow the irregular contact with igneous porphyritic rocks. At the main shaft, limestone is recrystallized to coarse-grained calcite. Nearby, it is altered to garnet and calcite. Most of the mined material in the Apache ore body consisted of sedimentary rocks cut by sulfide-filled fractures containing little or no calc-silicate minerals. Veins with andradite garnet, epidote, hematite, fluorite, and chalcopyrite exist locally. Ore minerals include galena, sphalerite, and associated cerargyrite in a gangue of calcite, garnet, limonite, and pyrite. Scheelite, cuproscheelite, and bismuthite were identified in dump samples of recrystallized limestone (Strongin, 1958). The richest ore shipped from the Apache Mine contained 0.05 oz/short ton Au, 12.7 oz/short ton Ag, 21 percent Pb, 4 percent Cu, and 25 percent Zn (Elston, 1960). Dump and chip samples collected in the mid-1980s assayed as high as 1.3 percent Cu, 800 ppm Mo, 6.0 percent Pb, 0.2 percent Zn, and 5.1 oz/short ton Ag (Peterson, 1976).

Daisy Mine, a carbonate-hosted lead-zinc replacement deposit confined to northeast-trending fault zones, consists of fissure-filling veins and replacements in brecciated limestone. Deposits are similar to those in Fremont mining district. Veins pinch and swell, but are about 0.6-1.0m thick. Stringers of iron and copper minerals occur in breccia and replace limestone adjacent to faults. Chalcopyrite and pyrite occur in quartz-calcite veins; native bismuth and tenorite have been reported. Oxidized minerals include malachite, azurite, chrysocolla, jarosite, hematite, limonite, and pyrolusite (Strongin, 1957). A sample assayed 0.4 percent Cu, 22 ppm Mo, 850 ppm Pb, 625 ppm Zn, and 2.1 oz/short ton Ag (Peterson, 1976).

Quartz veins, locally containing lead, silver, and copper, cut andesite of the Last Chance Formation and basalt and rhyolite dikes (Strongin, 1958). Extent of the quartz veining is not known. Chloritic alteration is common along the veins. Samples at Chapo Mine assayed as high as 2.61 percent Cu, 5.95 percent Zn, 4.72 percent Pb, 0.01 oz/short ton Au, 1.5 oz/short ton Ag, and 0.004 percent Mo (unpublished data, NMBMMR). A sample from Luna Mine assayed 2.0 percent Cu, 225 ppm Mo, 5.2 percent Pb, and 2.8 percent Zn, whereas a sample from Summertime Mine assayed 1.1 percent Cu, 66 ppm Mo, 200 ppm Pb, and 100 ppm Zn (Peterson, 1976). Gold assays from various pits range as high as 0.91 ppb Au (Griswold and others, 1989).

Little exploration has been conducted in the district. Favorable areas for exploration might be at intersections of the marbleized limestone, areas adjacent to the Indian and McKinley-Chapo faults, and other north- or northeast-trending faults (Strongin, 1958; Elston, 1960). Anomalously high concentrations of As, Be, Bi, Cd, Co, Cu, K, La, Mn, Mo, Pb, Sb, Th, U, Y, and Zn occur in stream-sediment samples collected from drainages in the area (Hassemer and Marsh, unpublished data, 1995).

Fremont District

Location, Mining History

Fremont mining district, discovered in 1860, is located in the northwestern Sierra Rica at the Luna and Hidalgo County border about 25 km southeast of Hachita; the international boundary is the southeastern border of the district), and most mineral deposits are in Mexico. In the past, the Fremont mining district has produced small amounts of base and precious metals from volcanic–epithermal veins and carbonate-hosted lead-zinc replacement deposits (Sutphin, chapter 2, this volume) (McLemore, 1995a; McLemore and Lueth, 1995). Production is reported as 190,000 lbs Pb, 10,000 oz Ag, 2,000 lbs Cu, 10 oz Au, and 4,000 lbs Zn (**table 5-2.18**), most from the International Mine in the eastern part of the area. Other mines in the district have had little or no production.

Since the discovery of lead, zinc, copper, silver, and gold deposits in 1880, the International Mine has produced approximately 879 short tons of ore (Griswold, 1961). The best ore was a 10 short-ton shipment grading 40 percent Pb and $62 per ton silver (at 95 cents per oz; Lindgren and others, 1910). Between 1910 and 1959, 14 railroad cars (approximately 50 short tons each) and an additional 129 short tons were shipped. Additional shipments were probably not reported.

District Geology

Fremont mining district is on the edge of the Apache Hills caldera and forms the eastern part of the intermediate zone of the Cordilleran orogenic belt (Drewes, 1991; see Bartsch–Winkler, chapter 4, this volume) (**table 5-2.19**); thrust faults are common. Paleozoic carbonate rocks and Cretaceous clastic rocks are overlain by Tertiary volcanic rocks (mainly Chapo Formation) and intruded by quartz monzonite and monzonite stocks that are 27 Ma (K-Ar, feldspar; Peterson, 1976; Deal and others, 1978). Rhyolite, latite, felsite, and lamprophyre dikes are common. Limestone is silicified, and volcanic rocks exhibit argillic alteration. The area is associated with gravity and magnetic highs (see Abrams and Klein, chapter 3, this volume), low aeroradiometric K and Th, and slightly elevated aeroradiometric U (see Pitkin, chapter 3, this volume). All are characteristic of mineralized carbonate rocks in the Mimbres Resource Area. Only a few localized geochemical anomalies (As, Bi, Cd, Pb, and Sb) are found in stream-sediment samples from the area (Hassemer and Marsh, unpublished data, 1995).

Mineral Deposits

Napone (or Nutshell) Mine, discovered in 1894, yielded several hundred short tons of lead-zinc ore prior to 1949. In 1953, 9.23 short tons of ore were produced that contained 35.06 lbs (0.19 percent) U_3O_8 and 3.69 lbs (0.02 percent) V_2O_5 . The deposit, approximately 214m long, consists of replacement bodies and veins along bedding fractures and faults. Ore bodies are *en echelon*, and occur in extensively brecciated and silicified limestone. The depth of the mineralization is not known. Uranium minerals (carnotite, autunite) are locally distributed in ore bodies consisting of galena, cerussite, smithsonite, sphalerite, pyrite, chalcopyrite, calcite, siderite, and quartz. A selected sample contained 0.13 percent U_3O_8 and 127 ppm Th (McLemore, 1983) and May and others (1982) reports one assay of 0.47 percent U_3O_8. Ore assays range as high as 45.8 percent Pb, 30.8 percent Zn, and 1.03 oz/short ton Ag (unpublished data, NMBMMR).

International Mine exploits a 1,220-m–long volcanic-epithermal vein in a fault cutting Lower Cretaceous sandstone, shale, and limestone conglomerate. The vein is mineralized for about 610 m, but about 305m is in Mexico (Griswold, 1961). The vein is 0.3-3.0m wide on the surface, averaging about 1.2m in width. Beds are contorted near the vein, suggesting left-lateral

movement along the fault. The vein follows a 1.5m–thick band of reddish fault gouge that was recemented with silica and calcite during mineralization (Griswold, 1961). Ore minerals are galena, sphalerite, and chalcopyrite; gangue is quartz, calcite, iron oxides, and pyrite. Gold and silver are present, and oxide minerals are exposed.

Eagle Mine consists of replacement bodies in limestone, and minor veining along a fault striking N. 05° E. (Elston, 1960). The mine produced in the 1880s and again in 1906-1907, yielding 200 short tons of argentiferous galena that averaged 40 percent Pb and 20 oz/short ton Ag (Lindgren and others, 1910). Galena with quartz and calcite has replaced limestone with little or no recrystallization; iron staining is prevalent at the surface. Tungsten and bismuth have been reported to occur locally within the vein (unpublished data, NMBMMR).

Numerous other prospects and mines occur in the area. Most are shallow, and the mineral potential at depth is not known. A core-drilling program could locate additional ore in the vein (Griswold, 1961). A perlite deposit was reported in the volcanic hills north of the Sierra Rica, but the occurrence has not been verified (Griswold, 1961).

MINERAL OCCURRENCES AND MINING DISTRICTS OF LUNA COUNTY

by

Virginia T. McLemore, NMBMMR,

and David M. Sutphin, USGS

INTRODUCTION

The first reported exploration of Luna County did not occur until the 1870s with the discovery of the Cookes Peak, Florida Mountains, and Victorio districts. Luna County was established from the western part of Doña Ana County in 1901. Since the 1870s, copper, gold, silver, lead, and zinc have been produced from the county (**table 5-3.1**). The Cookes Peak district ranks 5th in lead production and 9th in zinc production and the Victorio district ranks 7th in lead production in New Mexico (McLemore and Lueth, 1995). Currently, agate, manganese, clay, and sand and gravel are being produced from Luna County (Hatton and others, 1994). Two mills that operated in Deming in the 1990s are now closed: Southwest American Minerals (manganese) and Cyprus Piños Altos Deming (copper, zinc, silver, gold) (Hatton and others, 1994).

CARRIZALILLO HILLS

Carrizalillo District

Location, Mining History

Carrizalillo district (Cedar Hills or Stonewall districts) is a broad region in southwestern Luna County that includes Carrizalillo Hills, Cedar Mountains, and Klondike Hills (**figure 5-3.1**); Cedar Mountains WSA is within the district boundary. Scattered mineral occurrences in all three ranges consist of volcanic-epithermal and Rio Grande Rift lead-zinc deposits (**table 5-3.2**).

The district was first prospected in the late 1800s, but little is known of the mining history and development. Numerous pits, shafts, and a few adits occur in the area; none are extensive. Ruins of a smelter occur near Hermanas (sec. 22, T.28S., R.11W.). Only a small area is disturbed, with little slag, suggesting that production was probably small (Gates, 1985).

Copper, gold, silver, and lead production during the late 1800s, 1947-1948, and 1956 was minor. Less than 1,000 oz of silver and less than 1,000 lbs each of copper and lead were produced in 1947-1956. Recent exploration, including that by Canyon Resources, Dome Exploration (in 1985), Westmont (in 1989), and FMC Corporation, has apparently failed to discover minable deposits.

District Geology

Carrizalillo Hills and Cedar Mountains consist predominantly of volcanic rocks, including Tertiary calc-alkaline basaltic and andesitic flows, rhyolitic ash-flow tuffs, and volcanic breccias intruded by calc-alkaline, peraluminous rhyolite dikes and domes (Griswold, 1961; Bromfield and Wrucke, 1961; Varnell, 1976; Thorman and Drewes, 1981; Gates, 1985; Seager and Clemons, 1988; see Bartsch-Winkler, Chapter 4, this volume). Cedar Mountains form a homocline that is offset by mainly northwest-trending normal faults. In the southern Cedar Mountains and Klondike Hills, Cambrian through Cretaceous sandstone, shale, and limestone rocks are exposed. In the Klondike Hills, Proterozoic granite (1,390 Ma; Rb/Sr) is exposed and overlain by Cambrian to Cretaceous sedimentary rocks (Rupert, 1986; Rupert and Clemons, 1990).

Mineral Deposits

Small, discontinuous volcanic-epithermal and Rio Grande Rift deposits are scattered throughout the area (**figure 5-3.1**). Volcanic– epithermal quartz veins and stringers with local galena, chalcopyrite, and sphalerite fill faults and occur along the contacts of rhyolite and andesite dikes in the Carrizalillo Hills. Calumet mine accounts for much of the production (**table 5-3.2**). A mineralized vein occurs at the contact between a rhyolite dike and andesite. The vein, less than one m wide, strikes N. 20° W. and dips 60° W.; it contains malachite, limonite, quartz, manganese oxides, and calcite (Griswold, 1961; Gates, 1985).

Minor production occurred in 1946 from the Hermanas mine. Assays of veins near Johnson Ranch range to as much as 0.18 oz/short ton Au, 16.88 oz/short ton Ag, and 35,200 ppm Cu (Gates, 1985); quartz veins and breccia zones are as much as 6m wide. Manganese oxides, quartz, calcite, chrysocolla, malachite, and azurite are common.

In the Cedar Mountains, Lucky mine is a carbonate-hosted lead replacement and vein deposit that lies along a northeast-trending fault in Paleozoic limestone (Griswold, 1961). Steeply dipping vein and replacement deposits contain galena, quartz, calcite, and malachite. Jasperoids are common.

In the Klondike Hills, localized zones in carbonate rocks of the Hachita Formation (Escabrosa Group) and Hitt Canyon Member (El Paso Limestone) are replaced by silica, copper, and lead minerals and form jasperoids. These zones are especially common along faults (Rupert, 1986).

Silicification and argillic alteration is widespread in limestone, andesite, and rhyolite in the Carrizalillo district (Griswold, 1961; Varnell, 1976; Gates, 1985; Seager and Clemons, 1988); the alteration may be responsible for a large, regional gravity low (see Abrams and Klein, Chapter 3, this volume). Jasperoid occurs as void fillings and replacement deposits in Paleozoic limestone

and locally contains trace amounts of pyrite, galena, barite, and malachite. Argillic alteration, characterized by chlorite, calcite, quartz, and, locally, epidote, increases in intensity toward many of the veins. Silicification and potassic metasomatism are also associated with quartz-calcite veins, and may include gold and silver. Potassic alteration is characterized by potassium feldspar, clay, sericite, chlorite, quartz, calcite, and iron oxide (Seager and Clemons, 1988).

The report of a molybdenum discovery in the area (Leonard, 1982) could not be confirmed during this study, but the geology, geochemistry, and alteration evidence suggest the potential for a deposit. Anomalous concentrations of As, Ba, Cd, Co, Cr, La, Mn, Sb, Th, and Y occur in stream– sediment samples throughout the area, but they are scattered and have low values (Hassemer and Marsh, unpublished data, 1995). Agates and geodes are produced from several pits in the area, but total production is unknown.

COOKES RANGE

Cookes Peak District

Location, Mining History

Cookes Peak district (Jose district) is the most productive district in Luna County. The district extends into the Cookes Range WSA (**figure 1-2**). The eastern group of deposits are known as the Cookes subdistrict; the western group of prospects are known as the Jose subdistrict. The district was discovered in 1876, and by 1900 ore was produced from carbonate-hosted Pb-Zn and polymetallic vein deposits (see Sutphin, Chapter 2, this volume). Production from 1876-1965 of lead, zinc, copper, silver, and gold, includes more than 50 million lbs Pb and 7,000 lbs Zn (**table 5-3.3**). Average grade produced in 1902-1947 was 15.3 percent Pb, 11.5 percent Zn, and 2.51 oz/short ton Ag (Griswold, 1961). In addition, 452 short tons of fluorite and 450 long tons of 33-46 percent Mn have been produced from carbonate-hosted deposits (**table 1-9**; Rothrock and others, 1946; Elston, 1957; Farnham, 1961). Newmont Exploration Ltd. examined the district in the late 1980s and drilled several holes, but the exploration results are unknown.

District Geology

Sedimentary rocks in the district range in age from Paleozoic to Cretaceous, form a plunging anticline, and unconformably overlie Proterozoic granite (Jicha; 1954). Mineral deposits are mostly contained in Fusselman Dolomite underlying Percha Shale. Cookes Peak consists of intrusive granodiorite porphyry, which is 38.8 Ma (biotite, K-Ar; Loring and Loring, 1980b). Dikes radiate from the center of the body, and fractures in the Cookes Peak district parallel some of these dikes.

Mineral Deposits

Major deposits of the Cookes Peak district are carbonate-hosted Pb-Zn replacement and vein deposits (**table 5-3.4**) and occur along northeast-trending fractures in Fusselman Dolomite that lie beneath jasperoid bodies and(or) iron-stained and silicified Percha Shale. The jasperoids contain fluorite, calcite, quartz, and localized pyrite and cerussite. Ore bodies range in shape from irregular bodies, tabular to kidney-shaped bodies (mantos), and pipe-like bodies (chimneys). Most are less than 30m long, 15m wide, and 6m thick (Jicha, 1954). They are controlled by faults, fractures, and, locally, by anticlinal folds. Veins along faults are common in the western portion of the district, locally widening to tabular replacement bodies (Elston, 1957). Individual mines rarely produced more than 2,000 short tons of ore (**table 5-3.5**)). Primary ore minerals are galena and sphalerite in a gangue of pyrite, fluorite, and ankerite (Jicha, 1954); oxide minerals include cerussite, smithsonite, and anglesite. Plumbojarosite was discovered in the district in 1905 (Clarke and others, 1905).

Lead typically exceeds zinc and copper in abundance in most mines. However, ore at the Summit mine averaged 16 percent Pb, 23 percent Zn, and 1.7 oz/short ton Ag (unpublished data, NMBMMR). Upper levels were oxidized and are mined out. Silicification (jasperoid) is prevalent, and surrounds most ore bodies; brecciation and recementation are common.

Small pockets of ore, typically polymetallic vein deposits, occur in the granodiorite porphyry and Sarten Sandstone. They contain quartz, pyrite, calcite, chalcopyrite, galena, and sphalerite. Veins were generally higher grade than the carbonate-hosted deposits, but much smaller in size (Jicha, 1954). Sulfide disseminations (typically pyrite and chalcopyrite) are locally present in granodiorite.

Fluorite and manganese are common in the district. Lookout and Section 27 mines were mined for fluorite. Ruth mine was the most productive manganese mine. Placer manganese deposits in the southern part of the district were worked in 1959 by Q.M. Drunzer (Griswold, 1961).

Most exploration in the district concentrated on extending the known ore bodies. Much of the Fusselman Dolomite west of the district may have potential, especially where it occurs beneath the Percha Shale and near jasperoids (Jicha, 1954); drilling is required to assess the potential. Local Ba, Be, Cr, and Mn anomalies occur in stream-sediment samples from the area (Hassemer and Marsh, unpublished data, 1995).

Old Hadley District

Location, Mining History

The Old Hadley (or Graphic) district [sometimes described as part of the Cookes Peak district (Griswold, 1961)] is located east of Cookes Peak district (**figure 1-1**) and adjacent to Cookes Range WSA. Production in 1880-1929 from volcanic-epithermal veins (see Sutphin, Chapter 2, this volume) is estimated at 150 oz gold, 550 oz of silver, and minor copper, lead, and zinc (**table 1-3**). ASARCO examined the district in the late 1980s and drilled at least one exploratory drill hole; results are unknown.

District Geology

Macho Andesite cut by numerous faults dominates exposures in the district; it is overlain locally by the Rubio Peak Formation latite-andesite (Jicha, 1954). Latite tuff in the Macho Andesite is dated as 41 Ma (biotite, K-Ar; Loring and Loring, 1980b). Silicification and argillic alteration are prominent; acid-sulfate alteration, characterized by alunite and kaolinite, is locally pervasive in Rattlesnake Canyon (Hall, 1978).

Mineral Deposits

Volcanic-epithermal veins in altered Macho Andesite in the Old Hadley district (**table 5-3.6**) are steeply dipping, and trend N.0-15˚W.-N.55-65˚E. The veins are up to 92m in length and less than 1.2m in width. Veins parallel faults and fracture zones, and are associated with gypsum, clay alteration, and silicification. Brecciation, silicification, vug filling, and recementation are common, indicating an epithermal origin. Veins contain chalcopyrite, galena, sphalerite, and oxidized minerals such as malachite, azurite, chrysocolla, cuprite, and melaconite in a gangue of quartz, barite, pyrite, iron oxides, sericite, chlorite, and other clay minerals (Jicha, 1954). Old Hadley district veins contain more gold, barite, and quartz than the veins in the Cookes Peak district. Anomalous concentrations of As, Bi, Cd, Mo, Pb, Sn, U, and Zn occur in stream-sediment samples in the area, and spotty concentrations of Ag and Sb are found locally (Hassemer and Marsh, unpublished data, 1995).

Fluorite Ridge District

Location, Mining History

Fluorite Ridge district is located approximately 16 km north-northeast of Deming, south of Cookes Peak, and south of the Cookes Range WSA. Deposits occur into two areas: (1) Lower Camp in the southeast part of the district, and (2) Upper Camp in the central part of the ridge. The district also includes the hills to the south that contain manganese deposits and Goat Ridge to the west.

Fluorite Ridge district was discovered in 1907 and began production in 1909. Three types of deposits occur in the district: (1) Rio Grande Rift barite-fluorite deposits, (2) epithermal fluorite veins, and (3) epithermal manganese veins (see Sutphin, Chapter 2, this volume). There has been no base- or precious-metal production from the district. Fluorite production from 1909 to 1954 is estimated to be 93,827 short tons (**table 5-3.7**); much of the ore was shipped to Deming. Saddler and Greenleaf mines are the largest fluorite producers. Less than 1,000 short tons of low-grade manganese ore has been produced from the southern part of the district, primarily from the Ruth and Starkey mines.

District Geology

Fluorite Ridge consists predominantly of granodiorite porphyry, which is similar to the dated intrusive rock in the Cookes Peak district (see above). A dike cutting the northern exposure of the porphyry on Fluorite Ridge has a date of 37.6 Ma (whole rock, K-Ar; Clemons, 1982d). Griswold (1961) interprets the Fluorite Ridge granodiorite porphyry as separate from Cookes Peak porphyry, but age determination on a cross-cutting dike would suggest that the two are of similar age. The porphyry is surrounded by Precambrian granite and Cambrian, Permian, Pennsylvanian, Cretaceous, and early Tertiary sedimentary rocks (Clemons, 1982d). Fluorite Ridge is faulted, and sedimentary rocks form a dome in the central part of the granodiorite porphyry stock.

Mineral Deposits

Numerous mines and prospects have developed the veins and fissures on Fluorite Ridge, mostly along faults and fractures and their intersections, where the largest veins occur (Rothrock and others, 1946; Russell, 1947b). Both northeast- and northwest-trending faults are present (Burchard, 1911). Tip-Top and Hilltop Spar deposits occur as fillings in solution cavities in limestone (Rothrock and others, 1946) and are typical of Rio Grande Rift barite-fluorite deposits elsewhere in the state (McLemore and Barker, 1985; McLemore and Lueth, 1995). Fluorite and quartz are predominant minerals in a gangue of calcite, clay, and rare barite and pyrite. Brecciation, crustification, vug filling, and recementation are common, and consistent with epithermal origin. Veins occur mostly in granodiorite porphyry, and range to 6m in width and 92m in length (Burchard, 1911; Rothrock and others, 1946). In 1911, ore grades ranged from 60.9 percent CaF_2 to 95.6 percent CaF_2 by using hand sorting techniques (Burchard, 1911); lower grades were shipped in later years.

Geochemical, fluid inclusion, and stable-isotopic data indicate that fluorite from Fluorite Ridge district was formed from low-salinity, low-temperature meteoric fluid (Hill, 1994). Fluorite occurs in Gila Conglomerate and in a basaltic dike at the Gratton mine, indicating a late Tertiary or early Quaternary age of deposition (Griswold, 1961).

Anomalous concentrations of As, Be, Ba, Cd, Cr, Cu, Mn, Pb, Th, Ti, and Zn occur in stream-sediment samples from the area (Hassemer and Marsh, unpublished data, 1995), suggesting potential for base- and precious-metal deposits at depth. Most veins at depth were not explored and fluorite resources probably remain, especially in the subsurface surrounding the ridge and in areas between the Greenleaf and Valley mines. In addition, travertine resources at Goat Ridge could be quarried for local use. The range is in a State geothermal resource area.

FLORIDA MOUNTAINS, LITTLE FLORIDA MOUNTAINS

Florida Mountains District

Location, Mining History

Florida Mountains district, discovered in 1876, is located east of Deming and includes the Florida Mountains south of Florida Gap (**table 5-3.8**). The district is adjacent to the Florida Mountains WSA. From 1880 to 1956, 5,000 lbs Cu, less than 10 oz Au, 8,000 oz Ag, and more than 30,000 lbs Pb, worth approximately $102,000, were produced from carbonate-hosted Pb-Zn and polymetallic vein deposits in the district. Mahoney and Silver Cave mines are the largest metal producers. In addition, 200 short tons of fluorite and 1,421 long tons of 22-30 percent Mn have been produced from epithermal veins (**table 1-5**; **table 1-9**; Rothrock and others, 1946; Farnham, 1961). Manganese was mined in the 1950s from veins on the southeast slopes during the Federal purchasing program.

District Geology

Florida Mountains are in the northern part of the Laramide thrust belt as defined by Drewes (1991) and lie along the projection of the Texas lineament (see Bartsch-Winkler, Chapter 4, this volume). Rocks in the area consist of Paleozoic to lower Tertiary sedimentary rocks overlying Proterozoic and Cambrian granite and syenite plutons. Tertiary rhyolite, diorite, and andesite intrude older rocks. Rhyolite west of Florida Peak was dated as 29.1 Ma (feldspar, K-Ar; Clemons and Brown, 1983). Laramide and Basin-and-Range tilting, thrusting, and uplift have deformed the rocks. The district coincides with gravity and magnetic highs (see Abrams and Klein, Chapter 3, this volume). Anomalous As, Ba, Be, Cd, Cr, Cu, La, Mn, Nb, Pb, Sn, Th, Y, and Zn occur in stream-sediment samples from the area (Hassemer and Marsh, unpublished data, 1995).

Mineral Deposits

Carbonate-hosted Pb-Zn replacement and polymetallic vein deposits occur throughout the district (**table 5-3.9**) (see Sutphin, Chapter 2, this volume). Carbonate-hosted deposits are typically in Fusselman Dolomite and follow fracture and(or) fault zones. Deposits occur as fissure veins or manto-replacement bodies that contain smithsonite, cerussite, malachite, azurite, barite,

quartz, calcite, and localized occurrences of galena and sphalerite (Griswold, 1961). Lead commonly exceeds zinc and copper in abundance. Typically, the deposits are less than 1.5m wide and several hundred meters long.

Polymetallic veins occur along fractures and faults within Proterozoic granite, Precambrian–Cambrian syenite, and Tertiary agglomerate (**table 5-3.10**). Park mine occurs along a fault that separates Proterozoic granite and Paleozoic sedimentary rocks. Production from these veins has been small, but they are locally higher in grade than the carbonate-hosted Pb-Zn replacement deposits. Veins are typically less than 1.5m wide, several hundred meters long, and have variable dip. They contain quartz, pyrite, calcite, iron and manganese oxides, chalcopyrite, and local galena, sphalerite, fluorite, and barite.

Fluorite occurs as vein deposits, void-filling deposits, and replacement deposits in limestone. Breccia and jasperoid are common. Most fluorite vein and fissure deposits occur along faults and fractures, with fluorite and quartz predominant in a gangue of calcite, clay, and rare barite and pyrite. Fluid-inclusion data from fluorite indicate formation from low temperatures (146˚C -194˚C) and low salinities (6.2-8.4 equiv. wt. percent NaCl) fluids, which suggests a meteoric origin (North and Tuff, 1986).

Waddell Atir mine was first prospected in 1910 (Williams and others, 1964), but there is no reported production. In 1980, Barite Corporation of America drove a 236-m long adit to intersect the vein, but did not find ore to produce. The vein strikes N. 60˚ E., dips 55˚ SE., and contains barite, fluorite, galena, calcite, and quartz. It is 1.5-3.7m wide, 60m long, and occurs in Precambrian-Cambrian syenite. A sample assayed 41 percent $BaSO_4$, 19.7 percent CaF_2, and 1.8 percent Pb (Williams and others, 1964)..

Epithermal and carbonate-hosted manganese deposits occur throughout the Florida Mountains. Veins and replacement deposits are typically less than one m wide; the largest replacement deposits at the Birchfield Mine are 2.5m wide. The deposits follow NE– striking bedding planes. Locally, they form cross-cutting pipe-like bodies (chimneys).

Little Florida Mountains District

Location, Mining History

Florida Gap separates the Florida Mountains from the Little Florida Mountains. Two types of deposits, epithermal fluorite veins and epithermal manganese veins, occur in the Little Florida Mountains district (also known as Black Rock)(see Sutphin, Chapter 2, this volume). No precious or base metals were produced from the district. Fluorite production, mostly from Spar Mine, is estimated as 13,428 short tons (McAnulty, 1978). Manganese production is reported as 19,527 long tons of ore and 21,393 long tons of concentrate (**table 1-9**; Farnham, 1961). The

Manganese Mine was one of the larger manganese mines in the district (DeVaney and others, 1942). In 1923, a small mill was erected at the Luna Mine for processing manganese (**table 1-10**; **figure 1-16**), but the gravity concentration was not efficient and the mill closed. Production of manganese ceased in 1959 when the Federal government stopped buying manganese.

District Geology

Little Florida Mountains consist predominantly of interbedded andesite, dacite, ash-flow tuff, rhyolite, and fanglomerate intruded by rhyolite domes and dikes (Lasky, 1940; Clemons, 1982d). An ash-flow tuff, near the base of the stratigraphic section is dated at 37 Ma (biotite, K-Ar; Clemons, 1982d), and rhyolite near Rock Hound State Park is dated at 24 Ma (whole rock, K-Ar, Clemons, 1982d). Seismic data indicate that 180m of volcanic rocks are present in the subsurface (see Klein and Abrams, Chapter 3, this volume).

Mineral Deposits

Deposits in the Little Florida Mountains consist of epithermal fluorite and manganese veins occurring in Tertiary volcanic rocks and fanglomerate (**table 5-3.10**); the fanglomerate is interpreted at about 24 Ma, or as being of similar age to the rhyolite (Clemons, 1982d) and the mineralization as younger. Silicification is common in breccias along faults (jasperoids; Lasky, 1940).

Fluorite and barite, along with manganese oxides, calcite, quartz, and rare pyrite and galena, occur in veins along fault zones (Griswold, 1961; McAnulty, 1978). Most veins are traced by the presence of prominent silicified breccias. The veins can be as much as 2m wide; most are less than one meter wide. Brecciation, crustification, and silicification, commonly present, are indicative of an epithermal origin. Ore grades are estimated as 20-60 percent CaF_2 (Griswold, 1961). Barite is predominant at the Apache Mine ($SE^1/_4$ sec. 7, T.24S., R.7W.), but fluorite is predominant at the Spar (Florida) Mine (secs. 7 and 8, T.24S., R.7W.). A sample at the Spar Mine assayed 74 percent $BaSO_4$ and 9.5 percent CaF_2 (Williams and others, 1964).

Manganese veins with manganese oxides occur along faults and fracture zones and as breccia cement in the fanglomerate (**figure 5-3.2**). Few ore shoots contained more than 60,000 short tons of ore (Lasky, 1940). Most deposits decreased in size and grade at depths of 61-122 m, where manganiferous calcite becomes more abundant (Farnham, 1961). The average grade is about 20 percent Mn, with varying amounts of silica, calcite, iron, phosphorus, and barite. Trace amounts of copper, lead, zinc, silver, and arsenic are present locally in some veins (Lasky, 1940), but cannot be recovered economically (Williams and others, 1964).

Barite and fluorite can be mined in the Little Florida Mountains if there is local demand. It is unlikely that manganese will be mined in the near future, owing to the low grade and thinness of the deposits. Lasky (1940) estimated that 550,000-1,000,000 short tons of manganese ore remained in reserve, but Farnham (1961) estimated the reserve to be less than 75,000 short tons of 10-18 percent Mn. Anomalous concentrations of As, Ba, Be, Cd, Cr, Cu, La, Mn, Pb, Ti, and Zn are found in stream-sediment samples from the area (Hassemer and Marsh, unpublished data, 1995).

Agates, geodes, and jasper are collected from Rock Hound State Park. Total production is unknown. Early Paleozoic limestone beds are mostly dolomitic, but are locally of high-calcium grade (Kottlowski, 1962).

GRANITE HILL

Camel Mountain-Eagle Nest Area

Location, Mining History

Camel Mountain-Eagle Nest area is located along the Doña Ana-Luna County boundary, west of the Potrillo Mountains in southeastern Luna County (**figure 5-3.3**). No production is known from the area; only a few shallow prospect pits and shafts have exposed the small, discontinuous volcanic-epithermal veins and carbonate-hosted lead-zinc and carbonate-hosted silver-manganese replacement deposits (**table 5-3.11**).

District Geology

The area consists of several small, isolated hills of poorly exposed igneous rocks that have intruded Paleozoic and Mesozoic limestone, such as Prospect Hill. Tertiary volcanic and sedimentary rocks form other hills, such as Camel Mountain (**figure 5-3.4**). Two of the more prominent hills are Eagle Nest, where Permian sedimentary rocks are exposed, and Granite Mountain, where granite of suspected Proterozoic age is overlain by Cretaceous and Tertiary sedimentary rocks (**figure 4-3.5**). Porphyritic andesite to diorite has intruded Proterozoic(?) granite and Cretaceous and Tertiary sedimentary rocks (Broderick, 1984; Seager and Mack, 1990). The hills were apparently uplifted along normal faults that were active during Basin-and-Range events (Seager, 1989). Seismic surveys indicate the presence of elevated velocity rocks within 275-365m of the surface, which could represent carbonate rocks (see Klein, Chapter 3, this volume). The hills are surrounded by blow sand and other Recent alluvial deposits.

Mineral Deposits

Camel Mountain prospects consist of volcanic-epithermal veins filling fault and fracture zones near a east-northeast-striking rhyolite dike. Veins contain of iron and manganese oxides, calcite, fluorite, and quartz. Two samples assayed 0.028 oz/short ton Au, no Ag, 7.2 and 9.6 ppm

Cu, 32 and 33 ppm Pb, 350 and 87 ppm Zn, and 0.06 and <0.20 ppm Hg (NMBMMR). Gese (1985) reports one assay of 0.2 oz/short ton Ag, 39 ppm Pb, 76 ppm Zn, and 2.1 percent Mn.

Prospect Hill prospects consist of small, discontinuous carbonate-hosted replacement bodies of quartz, calcite, barite, gehlenite, and clinohumite (Griswold, 1961); no metallic sulfides are present. Gehlenite and clinohumite are rare silicate minerals valued as mineral specimens (Griswold, 1961). Gese (1985) reports one assay of 55 ppm Zn; and sample collected for this study assayed 78 ppm Cu, 110 ppm Pb, 67 ppm Au, and <0.18 ppm Hg.

Eagle Nest area is a volcanic-epithermal vein of quartz, calcite, siderite, iron oxides, pyrite, barite, fluorite, sphalerite, and galena in a mafic dike along a northeast-trending fault (**figure 5-3.5**.; Broderick, 1984; Gese, 1985). Chloritic and sericitic alteration, locally pervasive, affect adjacent conglomeratic rocks. Gese (1985) reports an assay of 5.7 oz/ton Ag, 4.5 percent Pb, and 1.6 percent Zn from a dump sample.

No production is reported from this area. Geochemical anomalies in the stream-sediment samples are scattered and low, but anomalous concentrations of As, Co, Cr, K, Mn, and Ti occur locally (Hassemer and Marsh, unpublished data, 1995).

TRES HERMANAS MOUNTAINS

Tres Hermanas District

Location, Mining History

Tres Hermanas district, discovered in 1881, is located near Columbus in southern Luna County (**figure 5-3.6**). Total production of copper, gold, silver, lead, and zinc is unknown from the Laramide skarn and vein deposits in the district (see Sutphin, Chapter 2, this volume), but includes 200,000 lbs Pb and 1 million lbs Zn (**table 5-3.12**). Cincinnati, Hancock, and Mahoney Mines were active in 1905 (Lindgren and others, 1910); Mahoney Mine was in production until 1920 (Griswold, 1961). In 1906-1907, ore was shipped to the Mississippi Valley area for smelting (Lindgren, 1909). Results of exploratory drilling in the early 1980s are unknown.

District Geology

Tres Hermanas Mountains consist predominantly of a 50 Ma quartz monzonite stock (hornblende, K-Ar; Leonard, 1982) surrounded by a thick sequence of Paleozoic and Cretaceous sedimentary rocks and Tertiary volcanic rocks (Balk, 1961; Griswold, 1961; Leonard, 1982). Thrust faults are common. Many Paleozoic limestone units proximal to the quartz monzonite stock are metamorphosed (Homme, 1958; Homme and Rosenzweig, 1970). Chemical variation in older metaluminous andesites, dacites, and rhyolites, and younger alkaline rhyolite and latite occurs in the calc-alkaline rocks in the Tres Hermanas Mountains (Leonard, 1982).

Mineral Deposits

Two deposit types occur in the Tres Hermanas district (**table 5-3.13**): Laramide veins and Laramide Pb-Zn skarn deposits (see Sutphin, Chapter 2, this volume). Deposits are of Tertiary age, probably forming after intrusion of the quartz monzonite but prior to intrusion of the basaltic dikes (Griswold, 1961; Doraibabu and Proctor, 1973). Geochemical data are consistent with a source of mineralization in the quartz monzonite stock; locally, older bedrock contributed essential elements for mineralization (Doraibabu and Proctor, 1973).

The most productive deposits are the Laramide Pb-Zn skarn deposits in the Escabrosa Group limestone and overlying Pennsylvanian sedimentary rocks. Tabular to pod-shaped manto replacement deposits, commonly silicified, are controlled by fractures and faults, which trend both east-west and north-south (Griswold, 1961). Ore minerals consist predominantly of sphalerite, galena, chalcopyrite, willemite, smithsonite, and other oxidized lead-zinc minerals in a gangue of calcite, quartz, pyrite, and calc-silicate minerals (Wade, 1913; Homme and Rosenwieg, 1970). Skarns are locally common in limestone xenoliths and in the limestone units located adjacent to the stock. Scheelite is reported from tactite near South Peak (Griswold, 1961). Ore at the Mahoney Mine averaged 26.7 percent Pb, 34.5 percent Zn, and 5.9 oz/short ton Ag. Gold assays are as high as 1,500 ppb Au (Griswold and others, 1989). Mahoney and Lindy Ann Mines are the largest producers.

Fissure veins in quartz monzonite contain galena, willemite, smithsonite, and hydrozincite; samples assayed 29-37 percent Zn, 11-40 percent Pb, and 2 oz/short ton Ag (Lindgren, 1909). Veins occur along faults and fractures in Paleozoic clastic rocks, quartz monzonite, and Tertiary volcanic rock. The most productive veins (Cincinnati Mine) trend east-west; north-trending veins have been less productive (Doraibabu and Proctor, 1973). Cincinnati vein strikes N. 75° E., dips 75-80° S., and is 3,050m long. Most veins are less than 1.2m wide. Disseminated pyrite, chalcopyrite, sphalerite, and galena occur sporadically throughout the quartz monzonite stock, suggesting the potential for a copper and/or copper-molybdenum porphyry deposit. However, the stock is not extensively altered, as is typical copper-porphyry deposits. Exploratory drilling into the stock has failed to reveal economic concentrations (Griswold, 1961; unpublished data, NMBMMR).

Most mines in the Tres Hermanas district are shallow (only a few reach depths of 92-153 m). Deposits have not been explored to greater depths [including Mahoney and Cincinnati Mines (Griswold, 1961)]. Areas of pyrite disseminations occur in secs. 26, 27, T.27S., R.9W. Anomalous concentrations of As, Ba, Be, Co, Cd, La, Mn, Mo, Pb, Sb, Th, Ti, Y, and Zn are found in stream-sediment samples from the area (Hassemer and Marsh, unpublished data, 1995).

Locally, marble occurs adjacent to quartz monzonite surrounding the Tres Hermanas Mountains (Griswold, 1961; Leonard, 1982). The marble is medium to coarse grained, and contains local intercalated bands of garnet. The deposit is small, discontinuous, and not economic. Contact metamorphism has produced distinctive rocks locally. Onyx, lavender spurrite rock, and cave deposits of fluorescent aragonite have been quarried. Yellow and white travertine (Mexican onyx) occurs in bands up to 1.5m thick within latite on the southern slopes of the Tres Hermanas Mountains (sec. 24, T.28S., R.9W.). Travertine could be mined for local use. Spurrite occurs within a limestone xenolith in quartz monzonite on the east slope of South Sister Peak (Griswold, 1961). It is a rare pale-gray to purple mineral, is valued by collectors, and is used as an ornamental stone.

Units in the Escabrosa Group limestone are locally high in calcium content (98.8 percent; Kottlowski, 1962), but the extent of the high-calcium types is not known. Many are dolomitic and contain chert. Early Cretaceous limestones are more than 467m thick and are locally of high-calcium grade (Kottlowski, 1962).

VICTORIO MOUNTAINS

Victorio District

Location, Mining History

Victorio district, discovered in the late 1800s, is in central Luna County, west of Deming (**figure 5-3.7**). Production of carbonate-hosted lead-zinc (silver, copper) deposits (see Sutphin, Chapter 2, this volume) began about 1880. Most early production was from the Chance and Jessie Mines, where lead, zinc, and silver were produced (Jones, 1904; Lindgren and others, 1910). An estimated 70,000-130,000 short tons of ore were mined from Victorio district between 1880 and 1957, yielding lead, zinc, silver, gold, and copper, and including 17.5 million lbs lead and more than 60,000 lbs zinc (**table 5-3.14**; McLemore and Lueth, 1985).

Beryllium and tungsten contact-metasomatic deposits (see Sutphin, Chapter 2, this volume) were discovered in the Victorio Mountains in the 1900s (Griswold, 1961; Holser, 1953; Dale and McKinney, 1959). In 1942, approximately 20,000 short tons of ore containing an average of one percent WO_3 were produced from Irish Rose claim (Dale and McKinney, 1959). Ore mainly contained scheelite, with lesser amounts of galena, smithsonite, and helvite. In addition, 19.6 short tons of 60 percent WO_3 (Hobbs, 1965) were produced from the mine. No production has taken place since 1957.

Recent exploration has been modest. In 1977-1983, Gulf Minerals Resources, Inc. delineated a subeconomic molybdenum-tungsten-beryllium deposit (see Sutphin, Chapter 2, this volume) northwest of Mine Hill. At a cutoff grade of 0.02 percent WO_3, resources were estimated

at 57,703,000 short tons of 0.129 percent Mo and 0.142 percent WO_3. Open-pit resources were estimated at 11,900,000 short tons of 0.076 percent WO_3 and 0.023 percent Be (Bell, 1983). In 1987-1988, Cominco American Resources examined the district for gold potential, and other exploration companies have examined the district in recent years. Results of these exploration efforts are unknown.

Most workings are on Mine Hill in the southern part of the Victorio Mountains (Griswold, 1961). Several shafts are 84m deep and underground workings are extensive (Griswold, 1961). Most workings were closed in 1994 by the New Mexico Abandoned Mine Lands Bureau.

District Geology

The district is part of the Laramide thrust belt as defined by Drewes (1991) and lies within the Texas lineament zone. Paleozoic and Cretaceous rocks (mostly limestone) are intruded by porphyritic stocks and overlain by volcanic rocks. The crest of the mountains consists of volcanic rocks dated at 42 MA (zircon from andesite; fission-track; Thorman and Drewes, 1980). Rocks dip northward and are offset by faults. Victorio granite is dated as 32 Ma (K/Ar, biotite; Bell, 1983) and the granite porphyry at the Irish Rose Mine is dated as 36 Ma (K/Ar, Bell, 1983).

A large gravity anomaly, which corresponds to near-surface carbonate rocks, is present in the district (see Abrams and Klein, Chapter 3, this volume). Seismic data indicate these rocks are within 732m of the surface (see Klein, Chapter 3, this volume). The area is characterized by a slight aeromagnetic radiometric U anomaly with low K and Th, which is characteristic of mineralized carbonate rocks in southwestern New Mexico (see Pitkin, Chapter 3, this volume).

Mineral Deposits

Two deposit types are present in the Victorio Mountains (**table 5-3.15**): carbonate-hosted lead-zinc replacement and tungsten-beryllium (Mo) vein and tactite deposits (Richter and Lawrence, 1983; North and McLemore, 1986). A subeconomic stratiform, pyrometasomatic Mo-W-Be deposit was delineated northwest of Mine Hill by Gulf Mineral Resources, Inc. (Bell, 1983).

Carbonate-hosted lead-zinc replacement deposits occur as oxidized replacement and vein deposits within Ordovician and Silurian dolomite and limestone (**figure 5-3.8**). Some veins are as much as 275m long. The most productive deposits occur along faults or fractures that strike N. 30-65° E. and dip steeply to the east (**figure 5-3.9**). Brecciation, dissolution, and recrystallization of dolomite is common near the mineral deposits. Faults exhibit both pre- and post-mineralization movement (Griswold, 1961). Ore minerals include galena, smithsonite, cerussite, and anglesite, with rare sphalerite and chalcopyrite, in a gangue of quartz, calcite, and iron oxides. Lead typically exceeds zinc and copper in abundance. Ore at the Rambler Mine

averaged 12.5 percent Pb and 3.9 percent Zn (unpublished data, NMBMMR). Gold assays range as high as 5,500 ppb Au (Griswold and others 1989).

Tungsten and beryllium occurs in veins and tactites in Ordovician limestone and dolomite in near rhyolitic intrusives. Ore minerals include helvite, wolframite, scheelite, molybdenite, galena, sphalerite, and beryl in a gangue of quartz, calcite, and local grossularite, tremolite, pyroxene, idocrase, and phlogopite (Holser, 1953; Warner and others, 1959; Richter and Lawrence, 1983).

Gulf Minerals Resources, Inc. drilled 71 exploratory drill holes northwest of Mine Hill and discovered the subeconomic Mo-W-Be deposit at depths at 275-458m (Bell, 1983). Ore minerals include molybdenite, powellite, scheelite, beryl, helvite, bismuthinite, and wolframite.

Additional exploration for carbonate-hosted deposits is feasible in the alluvium-covered area surrounding Mine Hill. Anomalous concentrations of Be, Co, Mn, Pb, and Zn are found in stream-sediment samples from the area (Hassemer and Marsh, unpublished data, 1995).

MINERAL OCCURRENCES AND MINING DISTRICTS OF DOÑA ANA COUNTY

by

Virginia T. McLemore, NMBMMR,

and David M. Sutphin, USGS

INTRODUCTION

Doña Ana County, created in 1852, was one of the first counties in New Mexico. The mineral industry is important to the economy of Doña Ana County, although agriculture, construction, and light industry currently have greater importance. Metals production began in the 1830s in the Organ Mountains at the Stevenson– Bennett Mine (**table 1-2**; Dunham, 1935). By 1910, all 12 mining districts in the county had been prospected. Today, a large part of the county is located within the White Sands Missile Range (WSMR) and withdrawn from mineral entry (**figure 1-2**).

Most of past metal production was from the Organ Mountains district (**table 1-3**), the sixth most productive lead district in New Mexico (McLemore and Lueth, 1995). Current production from the county consists of aggregate (mainly sand and gravel), clay and shale for brick manufacture, scoria, travertine, and minor dimension stone (Hatton and others, 1994).

Two copper processing plants are located in El Paso, Texas: American Smelting and Refining Corp. (ASARCO) smelter and Phelps Dodge Corporation solvent extraction-electrowinning plant. Adjacent to the county, Eagle Mill near El Paso manufactures bricks for the nearby population centers, and Juarez, Mexico, has two cement plants, a hydrofluoric acid plant, and a brick plant.

CERRO DE CRISTO REY

Brickland district

Location, Mining History

The Brickland district is on the flank of Cerro de Cristo Rey (also known as Cerro de Muleros) in southern New Mexico at the junction of the boundaries of Dona Ana County, N. Mex., El Paso County, Tex., and Chihuahuya Mexico. Clay and shale for brick manufacture have been produced from these areas since the early 1900s. Currently, brick plants are located in U.S. (New Mexico) and Juarez, Mexico. Limestone quarried from Cretaceous rocks is used in cement manufacture (Kottlowski, 1962) and the limestone and silica sand are used for smelter flux at the ASARCO smelter in El Paso.

Geology

Clay and shale deposits in the Mesilla Valley Shale (Cretaceous) crop out on the eastern flank of Cerro de Cristo Rey laccolith. Quartz-rich layers in the overlying Anapra Formation are mined locally for use in aggregate and for silica flux used in the ASARCO Smelter in El Paso. Limestone occurs in the Buda Limestone and Edwards Limestone.

Mineral deposits

Clay and shale are mined by open-pit quarrying, followed by crushing, screening, and firing at 900°C-1,000°C (Ntisimanyana, 1990). Limestone was sproadically quarried from the Edwards Limestone by the Southwestern Portland Cement Co. A limestone sample contained 93.5 percent $CaCO_3$, 2.1 percent $MgCO_3$, 3.2 percent SiO_2, and 0.8 percent Al_2O_3 (Kottlowski, 1962). A limestone sample from the younger Buda Limestone contained 93.3 percent $CaCO_3$, 1.3 percent $MgCO_3$, 3.7 percent SiO_2, and 0.7 percent Al_2O_3 (Kottlowski, 1962). However, these limestone beds are intercalated with quartzose sandstone and shale and cannot yield mineable high-calcium limestone (Kottlowski, 1962).

DOÑA ANA MOUNTAINS

Doña Ana Mountains District

Location, Mining History

Mineral deposits of the Doña Ana Mountains district consist of volcanic-epithermal deposits that were discovered in 1900 (**table 5-4.1**). A small amount of copper, approximately 100 oz of gold, and 5,000 oz of silver have been produced (North and McLemore, 1986). Marble and tactite are locally common, suggesting potential for Pb-Zn and Au skarn deposits.

District Geology

Permian through Recent rocks in the Doña Ana Mountains were tilted and uplifted in Late Tertiary time (Seager and others, 1976). Permian through Eocene sedimentary rocks are intruded by Eocene andesite and Oligocene monzonite. Eruption of the 763-m-thick 34-Ma Doña Ana rhyolite (ash-flow tuff) initiated collapse of the Doña Ana caldera, which was subsequently filled with rhyolite flows, ash-flow tuffs, domes, and breccias. Rhyolite and monzonite dikes intrude older rocks that underlie and surround the caldera. The area is characterized by gravity and magnetic highs, interpreted to relate to the caldera and subsequent intrusions. The area is also characterized by elevated radiometric U, Th, and K, that are interpreted to indicate rhyolitic rocks near calderas (see Pitkin, this volume).

Mineral Deposits

Piedra Blanca prospect (sec. 15, T.21S., R.1E.) consists of thin quartz veins along a 1.2-m–wide rhyolite dike that strikes N.80˚W. and dips 85˚N. The dike intrudes Cleofas Andesite

(Seager and others, 1976). Silicification of the rhyolite and andesite is pervasive (Seager and others, 1976). Several shallow pits and 3 shafts (25 m, 8 m, and 15m deep) have exposed the deposit (Dunham, 1935; Seager and others, 1976). Occurrences (sec. 15, T.21S., R.1E) are found along a north-trending dike, where 6-m shaft and pits expose thin quartz veins containing traces of pyrite, and like veins occur near Dagger Flat (sec. 20, T.21S., R.2E.) and are exposed by shafts 15m and 8m deep, a cut, and a shallow pit (Seager and others, 1976). Quartz and malachite occur along fractures in the Cleofas Andesite. Several prospects northwest of Doña Ana Peak have exposed manganese veins (**table 5-4.1**).

In 1913, two separate assays were made on a high-grade ore shoot. Assays of veins indicated 13.5 oz/ton Au, 1,835 oz/ton Ag and 13.6 oz/ton Au and 1,526 oz/ton Ag (Dunham, 1935). Another sample assayed 6.6 percent Mn (Farnham, 1961) (**table 5-4.2**). The vein is less than 0.5m wide and consists of quartz, iron oxides, manganese oxides, chlorite, calcite, and pyrite (Dunham, 1935; Farnham, 1961; Seager and others, 1976).

Marble and tactite in this region appear similar to mineralized skarns elsewhere in the Mimbres Resource Area. Marble has been quarried for local use as rip-rap and road fill (secs. 10, 15; T.21S., R.1E.); it varies in color from white to pink, but is highly fractured and contains impurities rendering it unsuitable for use as dimension stone. Traces of iron oxides, pyrite, and chalcopyrite are found, but the metal potential is probably low. A sample of mineralized marble assayed 6.12 oz/short ton Ag (unpublished data, NMBMMR). Tactite consists of fine-grained garnet and iron oxides with traces of pyrite (sec. 15, 16; T.21S., R.1E.).

Bursum Formation and Hueco Group may contain localized occurrences of high-calcium limestone of unknown extent (Kottlowski, 1962). They are marbleized locally near intrusives.

POTRILLO MOUNTAINS

Potrillo Mountains District

Location, Mining History

Potrillo Mountains, southeast of Las Cruces, form a continuous ridge 11-13 km long that rises above the Potrillo basalt field (**figure 4-4.27**). The district was discovered in 1883, but little is known of the early discovery or prospecting in this isolated region outside of the basalt field. Dunham (1935) and unpublished reports indicate that some gold, copper, silver, and possibly lead were produced from the area in the late 1800s and early 1900s, but production figures are missing. Heylman (1986) reports that John Graham discovered a pocket of gold in Cretaceous quartzite in the northern East Potrillo Mountains. It is unlikely that total production exceeded more than a few thousand dollars. Mines and prospects are listed in **table 5-4.3** and located in **figure 5-4.1**.

In 1970, the EPM (East Potrillo Mountains) mining claims were filed in the northeastern part of the range by J. Peter Rogowski and William A. Bowers (Jenkins, 1977). Subsequently, several companies, including Phelps Dodge Corporation, Anaconda Minerals Corporation, and Exxon Minerals, Inc., examined the area, but no ore discoveries have been announced. Exxon drilled 10 holes to depths ranging from 8m to 142m and located several mineralized zones containing high silver values (Gese, 1985). There is no current activity in the East Potrillo Mountains.

District Geology

East Potrillo Mountains consist of approximately 1,342m of sedimentary and volcanic rocks ranging in age from Permian through Holocene (**figure 4-4.6**)(Bowers, 1960; Jenkins, 1977; Seager and Mack, 1994). Permian and Cretaceous sedimentary rocks crop out in both the East and West Potrillo Mountains and are surrounded by Quaternary basaltic flows. Mt. Riley and Mt. Cox, northwest of the East Potrillo range, are composed of fine-grained microporphyritic andesite, rhyodacite, and rhyolite --probably the remnants of one viscous lava dome (Millican, 1971; Seager and Mack, 1994). Clastic rocks correlated with the Love Ranch Formation and volcanic rocks of the Rubio Peak Formation crop out along the flanks of Mt. Riley and Mt. Cox (Seager, 1989). A concealed pluton is indicated by a zone of high seismic velocity at a depth of 640m (Klein and Abrams, this volume) and a large gravity anomaly (Abrams and Klein, this volume). Age determination of the Mt. Riley rhyolite is reported as 32 Ma (K-Ar, whole rock, Marvin and others, 1988).

Mineral deposits occur in Permian limestone and locally in Cretaceous sandstone exposed in the East Potrillo Mountains (**figure 5-4.1**). East Potrillo Mountains are characterized by a distinctive aeroradiometric anomaly typical of carbonate-hosted mineral deposits in the study area --i.e., low K and Th concentrations, and slightly elevated U concentrations (Pitkin, this volume).

Mineral Deposits

Rio Grande Rift barite-fluorite deposits (see Sutphin, this volume) occur in limestone of the Hueco Group and San Andres Formation (Jenkins, 1977; Seager and Mack, 1994). Jasperoid is common in areas of mineralized limestone and is found throughout sec. 34, T.27S., R.7W., and secs. 3, 4, 9, 10, T.28S., R.2W. Jasperoid occurs in pods of varying sizes along faults, fractures, breccia zones, and bedding planes. The zones are brown, gray, yellow, and red, and consist of quartz, calcite, barite, and iron, manganese–oxides, and trace amounts of galena, pyrite, sphalerite, malachite, and cerussite. Jarosite is present locally (Jenkins, 1977), and includes brecciated, jigsaw-puzzle, xenomorphic, reticulated, granular, ribbon-rock (banded), and massive textures (Jenkins, 1977). Temperatures of homogenization (corrected for pressure) range from

185˚C to 238˚C (Jenkins, 1977). In several studies, geochemical sampling of jasperoids exposed at the surface indicate the presence of zones of anomalous values of silver, copper, lead, zinc, molybdenum, and other metals [Jenkins (1977), Gese (1985), and Jones and others (1987)]. The area is characterized by anomalously high stream-sediment sample concentrations of Zn and spotty As, Ba, Co, Mn, and Ti (Hassemer and Marsh, unpublished data, 1995).

Travertine Deposits

Travertine occurs in the southern East Potrillo Mountains (sec. 24, T.28S., R.2W., **table 5-4.3**). The travertine has been described as marble, but is probably a fissure-ridge type of travertine deposit that is fault-controlled (Barker and others, 1995). A quarry approximately 92-122m long and 30m wide, and a 4.6-m decline, exposes the deposit. Production is unknown, but is presumed to be insignificant, owing to the small quarry. A stockpile of travertine mixed with limestone and calcareous soil remained at the site in 1993.

Travertine is white with thin black bands (up to several cm wide). Most occurs in small pods or blocks that are fractured and broken; the largest slabs are only a few meters wide. The travertine is associated with recrystallized limestone of the Hueco Group (Hoffer, 1976; Seager and Mack, 1994) and occurs along the range-bounding fault (Robledo fault of Hoffer, 1976. The host limestone strikes N.10˚W. and dips 25˚W. The deposit is too small and fractured to have any major potential as dimension stone, but could be used locally as decorative stone or as road fill.

Other Deposits

Scoria deposits encompassing over 500 km^2 are found in the Potrillo Mountains and adjacent areas. More than 150 cinder cones occur in this area (Seager and Mack, 1994) and only a few have been quarried (see McLemore, this volume). In the West Potrillo Mountains, Mt. Riley, and Aden Lava Flow WSAs, Kilburn and others (1988) estimate an inferred resource of 100 cu m.

FRANKLIN MOUNTAINS (NORTHERN PART, NEW MEXICO)

Northern Franklin Mountains District

Location, Mining History

Northern Franklin Mountains district, discovered in 1914, is the New Mexico portion of the Franklin Mountains. A small amount of lead and silver were produced from a sedimentary–hydrothermal deposit (see Sutphin, this volume) (unpublished data, NMBMMR). Jarosite and gypsum also have been produced from the area (**table 5-4.4**).

District Geology

Northern Franklin Mountains consist of folded Ordovician through Permian carbonate and shale deposits (Harbour, 1972; Kelley and Matheny, 1983), and localized north-trending low- and high-angle normal faults (Kelley and Matheny, 1983). Quaternary piedmont and alluvial deposits

form the lower foothills. The area is characterized by a distinctive aeroradiometric anomaly that is typical of carbonate-hosted mineral deposits in the study area --i.e., low K and Th concentrations, and slightly elevated U concentrations (Pitkin, this volume).

Proterozoic rocks correlated with the Mundy Breccia and Lanoria Quartzite underlie Paleozoic rocks in Hitt Canyon, just south of the New Mexico-Texas state line (Harbour, 1972). Proterozoic granite porphyry and granite are also found in Hitt Canyon. Proterozoic rocks probably underlie the northern Franklin Mountains in New Mexico.

Mineral Deposits

Veins and replacement deposits of lead, barite, fluorite, calcite, iron oxides, and quartz occur in dolomitic limestones of the Fusselman Dolomite. Dunham (1935) reports an assay of 4 oz/ton Ag from one vein ($SE^1/_4$ sec. 32, T.25S., T.4E.) and small shipments of argentiferous galena. The largest vein is less than one meter wide and several hundred meters long. Brecciation and jasperoid are common locally. Local geochemical anomalies of Pb, Be, Zn, Mo, Sb, Cd, and As occur in stream-sediment samples (Hassemer and Marsh, unpublished data, 1995).

Copper is found in Proterozoic Castner Limestone marble near the contact with Proterozoic granite in Hitt Canyon, Tex. (Harbour, 1972; Deen, 1976; Goodell, 1976) Small, discontinuous contact metasomatic deposits at this locale consist of bornite, pyrite, covellite, chalcopyrite, marcasite, and pyrrhotite (Deen, 1976; Goodell, 1976). Shallow prospect pits have exposed the deposits; a sample assayed 5.84 percent Cu, 0.016 percent Pb, and 0.81 percent Zn (Goodell, 1976). In addition, iron deposits have replaced the Castner Limestone where the limestone has been intruded by granite, approximately 2.9 km south of the state line. Iron occurs as siderite and rarely exceeds 40 percent Fe (Harbour, 1972). Similar deposits may occur in New Mexico in Proterozoic rocks beneath the northern Franklin Mountains.

Jarosite

Copiapo jarosite mine is located in the northern Franklin Mountains at Webb Gap ($NE^1/_4$ sec. 8, T.26S., R.4E.). Development consists of a 60-m inclined shaft with 4 levels, and 6 prospect pits. Several hundred short tons of material were mined in 1925-28 by F. Schneider Co. for use as pigment in paint

The deposit occurs along a north-trending, low-angle, fault zone (strike N.10˚E., dip 40-50˚E.) within the Bishop Cap Formation of the Magdalena Group (**figure 5-4.2**); Kelley and Matheny, 1983). At the shaft, the deposit is 3-5m wide and extends for approximately 30-60 m. The deposit pinches out to the north. A drift at the 30-m level extends north for 6m and south for 92m (Dunham, 1935). The deposit thins to the south (less than 3m wide) for approximately

300m. The host limestone strikes N. 13˚ W. and dips 40˚W.

The deposit consists of veins and replacement bodies along the fault zone, and contains jarosite (red to yellow to orange), limonite, hematite (red to black to brown), gypsum, calcite, and aragonite. Malachite stains reportedly coat fractures at the bottom of the shaft (Dunham, 1935). Jarosite occurs only within the upper 30m (unpublished data, NMBMMR). Assays of selected samples range from 0-3.14 oz/ton Ag, 10-32 ppm Cu, 22-61 ppm Pb, 44-650 ppm Zn, and 2-55 percent Fe (NMBMMR samples 3050-3054). A crude zonation is present: adjacent to the footwall, black to dark–brown hematite and limonite is present in a zone about 0.3-0.6m wide; jarosite, limonite, and hematite of various colors form the central zone, which ranges from 0.6 to 1.0m thick; white calcareous to clayey material and cross-cutting zones of hematite and jarosite adjacent to the hangingwall form the outer zone.

Origin of the deposit is speculative. Mineralogy and crude zonation are suggestive of a supergene origin (minerals are poorly crystalline to very fine grained). Sulfur-isotope analyses are required to confirm a supergene origin. This deposit may overlie epithermal base- or precious-metal deposits; drilling would confirm their presence. The economic potential of this small deposit for future use as paint pigment is probably low, owing to its size and distance from paint manufacturers.

Additional small, isolated occurrences of jarosite, limonite, and hematite occur throughout limestone deposits in sections 22, 27; T.26S., R.4E. These occurrences are predominantly fracture coatings, are small and scattered, and uneconomical.

Gypsum and Limestone

Gypsum and limestone have been quarried in the northern Franklin Mountains from the Panther Seep Formation and lower Hueco Group. Gypsum occurs in two beds of the Hueco Group over 30m thick at Anthony Gap; each bed (Harbour, 1972). The gypsum was quarried around 1932 for use by the El Paso Cement Company (Dunham, 1935). Limestone also has been quarried in both New Mexico and Texas, probably for aggregate.

Lower and middle Pennsylvanian limestone beds and those in the Hueco Group may contain localized occurrences of high-calcium type, although they may contain considerable amounts of impurities (Kottlowski, 1962).

ORGAN-SAN ANDRES MOUNTAINS

Bear Canyon District

Location, Mining History

Bear Canyon district (also known as the Stevens or San Augustin district) is in the southern San Andres Mountains and extends northward from Bear Canyon north of Black Mountain to Little San Nicolas Canyon north of Goat Mountain. Shafts, adits, and prospect pits occur along the foothills (lower contact deposits) and near the crest (upper contact deposits) (**table 5-4.5**; **figure 5-4.3**). The district was discovered in 1900 by J. Bennett (Dunham, 1935; Talmage and Wootton, 1937) and production began a few years later. Less than 10,000 lbs of copper, less than 100 oz of silver, and some lead have been produced from the district (Dunham, 1935; McLemore, 1994). In 1932, 50 short tons of barite were produced from the Stevens Mine (Williams, 1966). The district lies entirely within the WSMR and is withdrawn from mineral entry.

District Geology

Bear Canyon district consists of westward-dipping, Cambrian through Mississippian sedimentary rocks in either fault or unconformable contact with Proterozoic granitic and metamorphic rocks (Dunham, 1935; Bachman and Myers, 1963, 1969). Low-angle thrust faults and normal faults, locally mineralized, in the southern part of the range have placed Proterozoic rocks over Ordovician and Cambrian sedimentary rocks (Dunham, 1935; Bachman and Myers, 1969) (**figure 5-4.4**). Younger sedimentary rocks of Pennsylvanian through Tertiary age overlie rocks west of the district. A series of probable Tertiary sills and dikes intrude sedimentary rocks south of Bear Canyon on Quartzite Mountain (Bachman and Myers, 1969; Seager, 1981). These sills are composed of sericitized quartz-feldspar porphyry. Basaltic dioritic dikes intrude the sedimentary rocks north of Bear Mountain and are highly altered and weathered (Bachman and Myers, 1969).

Mineral Deposits

Rio Grande Rift barite-fluorite-galena deposits (see Sutphin, this volume) are found scattered throughout the area in limestone and dolomite along the low angle fault between the Ordovician sedimentary rocks and Proterozoic granite in the foothills (lower contact deposits) and within Silurian dolomite beneath Percha Shale along the crest (upper contact deposits) (Dunham, 1935; Williams and others, 1964; Bachman and Myers, 1969; Smith, 1981; McLemore, 1994). Deposits consist predominantly of veins, breccia cement, cavity-fillings, and minor irregular replacement deposits along faults, fractures, unconformities, and bedding planes in dolomitic limestone. Percha Shale and Proterozoic granitic and metamorphic rocks may have acted as an impermeable cap for upward migrating mineralizing fluids. Barite, fluorite, calcite, and quartz are

predominant minerals in these deposits. Locally, galena, malachite, and wulfenite are found (C.W. Plumb, unpublished report, Nov. 1925, NMBMMR). Assays as high as 2.6 oz/short ton Ag, 12.2 percent Cu and 34.8 percent Pb have been reported (W.E. Koch, unpublished report, July 1911, NMBMMR). Samples collected for this study and assayed by NMBMMR show values as high as 5.4 ppm Ag, 5,000 ppm Cu, 51,000 ppm Pb, and 280 ppm Zn (sample nos. VM007R-VM012R). The assays are from selected samples and indicate the presence of local concentrations of metals in the deposits. Deposits along the upper contact near the crest are remote and inaccessible; those along the lower contact are small and low grade.

Black Mountain District

Location, Mining History

Black Mountain district lies on Black Mountain north of the Organ Mountains district in the southern San Andres Mountains. The district, also known as Kent, Organ, and Gold Camp districts, was discovered in 1883 by Pat Breen. Mountain Chief and Black Mountain Mines are the only productive mines in the district (**table 5-4.6**), producing less than 10,000 lbs of copper, 600 ounces of gold, less than 1,000 ounces of silver, 1,100 short tons of fluorite, and minor amounts of lead (**table 1-2**, **table 1-5**; Dunham, 1935; Williams, 1966; McAnulty, 1978; McLemore, 1994). The district is within the WSMR and closed to public access.

District Geology

Rio Grande Rift barite-fluorite-galena deposits (see Sutphin, this volume) are found scattered throughout the Black Mountain area and are hosted by El Paso Limestone dolomite and limestone that are in fault contact with Proterozoic granite and metamorphic rocks (Dunham, 1935; Talmage and Wootton, 1937; Seager, 1981). North- and west-trending faults cut the rocks. The area lies on a gravity gradient between a gravity high to the north and a gravity low to the south, which corresponds to the Organ Mountains batholith (see Abrams and Klein, this volume). Geochemical anomalies in stream-sediments from the area include elevated concentrations of Cu, Pb, Mo, Sb, and Zn (Hassemer and Marsh, unpublished data, 1995).

Mineral Deposits

Mountain Chief Mine ($NW^1/_4$ sec. 11, T.21S., R.4E.) is located on the south side of Black Mountain and consists of an 18–m shaft and prospect pits. It is an irregular replacement body in Fusselman Dolomite, containing gold, quartz, calcite, limonite, pyrite, and chlorite (Dunham, 1935). The relatively large amount of gold production reported is unusual for this type of deposit; the deposits were not examined during this study. Two additional, but minor, prospects are found in the district. Bighorn deposit (sec. 12, T.21S., R.4E.) consists of a 153-m adit in Paleozoic dolomite where irregular replacement bodies of galena were developed along a vein trending N.

R.50W. A small barite-galena deposit occurs at the summit of Black Mountain (sec. 1, T.21S., R.4E.)(Dunham, 1935). Percha Shale forms a cap on the deposit. None of these deposits are economic.

Organ Mountains District

Location, Mining History

Organ Mountains district includes the Mineral Hill, Bishops Cap, Gold Camp, Modoc, South Canyon, Soledad Canyon, and Texas Canyon subdistricts. Mineralization was discovered in the 1830s and perhaps as early as 1797 (Dunham, 1935). Metal production from the district amounts to $2.7 million worth of copper, lead, zinc, silver and gold (**table 1-3**; **table 5-4.7**). Other production from the Organ Mountains district amounts to 600 short tons of barite; 1,650 short tons of fluorite; 14 lbs of uranium; and 9 lbs of vanadium (**table1-5**, **table 1-6**, **table 1-7**). Bismuth occurs locally; a small amount was produced from the Texas Canyon Mine (Dasch, 1965) and other ore shipments were penalized for bismuth at the smelter. Uranium and barite were produced from the Bishops Cap area (Williams and others, 1964; McLemore, 1983). Local occurrences of Fe, Mn, Mo, Sn, Te, and W are also reported (**table 1-2**).

From the 1960s through the early 1980s, companies explored the Organ Mountains for copper-molybdenum porphyry deposits (see Sutphin, this volume). Kerr-McGee Mining Corporation drilled 18 holes in 1963; AMAX Inc. drilled 6 holes in 1969; Bear Creek Mining Company drilled 6 holes in 1970. Continental Oil Company (Conoco) drilled 14 holes in 1972-1976. In all, more than 60 drill holes were drilled northeast of Organ, ranging in depth from 60m to 945m (**figure 5-4.5**; Newcomer and Giordano, 1986). Studies of lithology, alteration assemblages, mineral zoning, and stockwork veining suggest that a copper and/or copper-molybdenum porphyry deposit may underlie the Organ Mountains district. Drilling has not delineated any ore bodies, but assays range from 0.001 to 0.065 percent Cu and as high as 0.15 percent Mo (Newcomer, 1984; Newcomer and Giordano, 1986). From 1989 to 1994 , the Abandoned Mine Lands Bureau reclaimed the Stevenson-Bennett, Modoc, Memphis, and several smaller mines in the vicinity of the Memphis mine.

District Geology

The Organ Mountains is a west-tilted block of rocks ranging in age from Proterozoic through Quaternary. The oldest rocks in the area are Proterozoic granitic rocks, which are overlain by as much as 2,593m of mostly marine Paleozoic sedimentary rocks (Seager, 1981); the rocks were deformed during the Laramide compressional event. In Oligocene time, the Organ batholith and volcanic rocks associated with the Organ caldera were emplaced (Seager, 1981; Newcomer and Giordano, 1986; Seager and McCurry, 1988). Organ batholith is a complex pluton made up

of multiple intrusions (Seager, 1981; Seager and McCurry, 1988) including three major phases -- granite of Granite Peak, Sugarloaf Peak quartz monzonite (34 Ma; McLemore and others, 1995), and Organ Needle quartz syenite. All are related to mineral deposits. Rhyolite dikes intrude the Organ batholith locally, and also are related to mineralization. Uplift and erosion produced the rugged topography characteristic of the Organ Mountains. A gravity low coincides with the Sugarloaf Peak quartz monzonite (see Abrams and Klein, this volume), and may result from widespread sericitic alteration.

Mineral Deposits

Six deposit types are distributed five zones in the Organ Mountains district (**table 5-4.8**; Dunham, 1935; Seager, 1981; Seager and McCurry, 1988). Copper-molybdenum deposits form a core, surrounded by zinc-lead, lead-zinc, gold-silver, and fluorite-barite deposits. This district-wide zoning is best preserved in the northern Organ Mountains, where disseminated copper and molybdenum occurrences, possibly representing a faulted portion of a copper-molybdenum porphyry deposit, has been encountered in drill holes northwest of Organ (Newcomer and Giordano, 1986).

A zone of disseminated and vein pyrite occurs to the east at San Augustin Pass in the Sugarloaf Peak quartz monzonite, the last and most volatile-rich phase of the Organ batholith. The zone is located in the northern part of the district. Silver-bearing pegmatites, dated as 31 Ma ($^{40}Ar/^{39}Ar$, K-feldspar), occur near San Augustin Pass in the Sugarloaf Peak quartz monzonite (Dunham, 1935; McLemore and others, 1995). Copper breccia deposits occur west of the Sugarloaf Peak quartz monzonite at the Torpedo and Memphis mines. A transition from disseminated copper and molybdenum to copper skarns and breccias to zinc-lead skarns and replacement deposits occurs in carbonate rocks northwest of the Memphis Mine and near the Excelsior Mine in the northern portion of the district (Lueth, 1988). Homestake and Memphis deposits are zinc-lead skarns; Merrimac Mine is predominantly a zinc replacement deposit. Lead with silver becomes more dominant to the east. Hilltop and Black Prince mines are predominantly carbonate-hosted lead-silver deposits; Stevenson-Bennett is a carbonate-hosted lead-silver and zinc-lead deposit (polymetallic replacement) (**figure 5-4.6**).

Gold and silver epithermal/mesothermal veins (see Sutphin, this volume) occur in the Proterozoic rocks in the Gold Hill area, east of the Sugarloaf Peak quartz monzonite (**figure 5-4.7**). Silver decreases to the north and barite becomes dominant. Modoc and Orejon Andesite deposits along the west side of the Organ Mountains are lead-zinc skarn and replacement deposits and may be related to a third copper-molybdenum zone in the central Organ Mountains near Organ Peak.(**figure 5-4.8**; **figure 5-4.9**). An outer zone, surrounding the Organ

Mountains batholith, consists of Rio Grande Rift barite-fluorite deposits, locally with copper, lead, silver, uranium, and vanadium; examples include Bishops Cap (**figure 5-4.10A**; **figure 5-4.10B**) and Ruby mines. Assays of samples from the district are listed in **table 5-4.9**.

Alteration and mineralization of the rocks and drilling evidence indicate that at least three copper-molybdenum porphyry systems may occur in the Organ Mountains, but the potential for an economic deposit is low (Schilling, 1965; Ludington and others, 1988). The potential for copper breccia, skarn, carbonate-hosted lead-zinc, epithermal/mesothermal vein, and fluorite deposits in the Organ Mountains is moderate (see Sutphin, this volume; Ludington and others, 1988). Other metals occurring in the district include bismuth (Dasch, 1965), tungsten (Dale and McKinney, 1959), tellurium, tin, and manganese. The Torpedo Mine contains an estimated 600,000 short tons of 5 percent Cu in reserves (Soulé, 1956). The Stephenson-Bennett Mine contains an estimated 35,000 short tons of ore grading 2.9 oz/t Ag, 10.55 percent Pb, and 13 percent Zn (Jeske, 1987). The Ruby Mine contains an estimated 230,000 short tons of 18 percent fluorite.

Marble

Marble occurs locally along the intrusive contact between the limestone and rhyolite-quartz monzonite porphyry north of Organ (Dunham, 1935; Seager, 1981). The marble is typically white, and locally contains disseminated pyrite, garnet, and epidote. One of the largest deposits is at Hilltop mine, where the adit penetrates approximately 90m of white marble interbedded with unaltered limestone. These marble deposits are of small size and at considerable distance to potential markets. Their location within the WSMR precludes mining.

San Andres Canyon District

Location, Mining History

San Andres Canyon district is in San Andres Canyon in the San Andres Mountains and consists of the San Andres lead deposit ($SE^1/_4$ sec. 18, T.18S., R.4E.), a Rio Grande Rift barite-fluorite-galena deposit (see Sutphin, this volume). The deposit was discovered and developed in 1900. Development consists of a 30-m open cut, 168-m adit with a 40-m drift, a winze, and several shallow pits and shafts (Dunham, 1935; Smith, 1981); all were caved and inaccessible in 1993. A mill and smelter were erected in 1900-1904 and consisted of a crusher, screens, rolls, and 15 jigs (**figure 1-16**; **table 1-10**). Capacity was expected to be 100 short tons per day. However, the mill and smelter were built before any reserves were delineated and the entire operation failed with very little lead and copper production (Dunham, 1935). Only mill and smelter foundations remain.

District Geology

Exposed sedimentary rocks range from Paleozoic to Cenozoic in age. The Cambrian to Cretaceous section totals about 2,195m (Kottlowski and LeMone, 1994). North-trending normal faults cut the sedimentary rocks in places (Bachman and Myers, 1969). Rio Grande Rift deposits are found in the Fusselman Dolomite.

Mineral Deposits

The deposit is a small, irregular replacement body in Fusselman Dolomite adjacent to a fault that strikes N.15˚W., and dips steeply to the west (Dunham, 1935; Bachman and Myers, 1963, 1969; Smith, 1981). The deposit is about 60m long and up to 6m wide (Dunham, 1935) and consists of barite, quartz, minor galena, calcite, fluorite, iron oxides, and clay. Samples collected for this report assayed as high as 2.2 ppm Ag, 170 ppm Cu, 24,000 ppm Pb, and 31 ppm Zn (USGS samples SA010R-SA012R). The deposit is characteristic of Rio Grande Rift deposits elsewhere in New Mexico (McLemore and Barker, 1985; North and McLemore, 1986).

San Andrecito-Hembrillo District

Location, Mining History

San Andrecito-Hembrillo district (T.16S., T.17S., R.3E., R.4E.) is in the San Andres Mountains in northern Doña Ana and southern Sierra Counties. The district includes the San Andrecito, Deadman, Lost Man, Hembrillo, and Hospital canyons and adjacent slopes. Rio Grande Rift barite-fluorite-galena, Precambrian vein and replacement (see Sutphin, this volume), and talc deposits are found in the district (**table 5-4.10**). Little information exists on the discovery, history, or production of these small deposits; many could not be located for this study. Green Crawford and Hembrillo Canyon prospects were worked in the late 1890s or early 1900s. Additional production occurred from the Green Crawford during 1920-1930 and from the Hembrillo Canyon prospects in 1914, 1915, and 1918 (Anderson, 1957; unpublished data, NMBMMR). Total metal production from the district probably amounts to less than $10,000 worth of copper (less than 10,000 lbs), lead, and silver (less than 100 oz) (Dunham, 1935; unpublished data, NMBMMR). Total talc production from 1920 to 1945 is approximately 12,062 short tons (Fitzsimmons and Kelley, 1980; Chidester and others, 1964). The district is within the WSMR and withdrawn from mineral entry.

District Geology

The oldest rocks exposed in the San Andrecito-Hembrillo district are Proterozoic granite, quartz-feldspar-mica schist, quartzite, amphibolite, phyllite, and talc schist. The rocks are metamorphosed and foliated, steeply dipping to the west, and have a regional strike of N.30-45˚W. Exposed sedimentary rocks range in age from Paleozoic to Cenozoic (Seager, 1994).

Cambrian to Cretaceous rock thicknesses total about 2,196m (Kottlowski and LeMone, 1994). Rio Grande Rift deposits are found in the Lead Camp Limestone and along faults in the Bliss Formation. Vein and replacement deposits containing base-, precious-metal, and talc deposits occur in Proterozoic rocks. A Tertiary andesite dike intrudes the sedimentary rocks at Victorio Peak and contains disseminated pyrite and chalcopyrite (F.E. Kottlowski, NMBMMR, oral commun., 6/15/95)

Mineral Deposits

Three types of deposits are found in the San Andrecito-Hembrillo district. Precambrian talc deposits are the most extensive, and reserves are still present. Rio Grande Rift barite-fluorite deposits are small, but all reported metal production is from these deposits. Minor vein and replacement deposits occur along faults and adjacent to amphibolite dikes in Proterozoic rocks in Hospital Canyon (south of Hembrillo Canyon).

Talc deposits occur in Proterozoic granite and metamorphic rocks in Hembrillo Canyon along the Sierra-Doña Ana county line (Chidester and others, 1964; Fitzsimmons and Kelley, 1980). Deposits are lens-shaped, measuring approximately 30m long and 2.4-3.7m ft wide. A reserve of 6,500 short tons is reported by Fitzsimmons and Kelley (1980). Development consists of adits and pits.

The central portion of the talc zone consists of nearly pure talc. The outer zone is 0.6-1.0m wide and consists of talc, carbonate minerals, and chlorite. Talc grades into banded quartz-chlorite phyllite and schist. Foliation is subparallel to the foliation of metamorphic rocks, indicating a Proterozoic age.

Rio Grande Rift barite-fluorite-galena deposits are present in Pennsylvanian Lead Camp Limestone and Ordovician limestones. Vein- and replacement-deposits occur along fault traces in the Bliss Formation at the Green Crawford mine.

The most extensive development is at the Green Crawford Mine ($NW^1/_4$, sec. 31, T.17S., R.4E.) and Hembrillo Canyon prospects ($SE^1/_4$, sec. 9, T.16S., R.3E.). Prospects were also found in Hospital Canyon ($SW^1/_4$, sec. 18, T.16S., R.4E.). Additional prospect pits reportedly occur in veins in Lost Man Canyon (Dunham, 1935; The Mining World, 4/23/1910, p. 868), but these prospects could not be located during this study. Green Crawford Mine development consists of two adits, several prospect pits, and shallow shafts on opposite sides of San Andrecito Canyon (**figure 5-4.11**). The north adit is approximately 30m long with a 9-m long winze and a

raise. Prospect pits and a shaft also develop portions of the north vein upslope from the adit. The south adit is less than 21m long with a 10m raise. Prospect pits and trenches also expose portions of the south vein.

The deposit consists of silicified veins, less than one meter wide and 30-90m long that occurs along two north-trending faults cutting sandstone of the Bliss Formation and El Paso Limestone and Montoya Group limestones (Seager, 1994). North of the canyon, the vein strikes N.55˚E. and dips 80˚E.; south of the canyon, it strikes N.25˚E. and dips 87˚E. Additional veins may be present in the area, but are covered by talus. Simple fissure-fillings consisting of covellite, chalcocite, chalcopyrite, cuprite, malachite, and azurite in a gangue of quartz, calcite, iron oxides, and trace barite. Chalcanthite coats some walls along the adits. Host rocks have been silicified and replaced by iron oxides adjacent to the veins. A sample of ore reportedly assayed 27.93 percent Cu, a trace of silver, and no gold (Dunham, 1935). Samples collected for this report assayed as high as 178,000 ppm Cu, 68 ppm Pb, 48 ppm Zn, and no detectable gold; one sample assayed 3.36 oz/short ton Ag (unpublished data, NMBMMR)). Analyses of samples collected for this study are given in **table 5-4.11**.

Hembrillo Canyon prospects consist of two shafts (4-m and 23-30-m deep) and two shallow prospect pits. The deposits may be part of the Lot OM-69 prospect described by Williams and others (1964). However, Williams and others (1964) place the Lot OM-69 prospect in sec. 10 instead of sec. 9, T.16S., R.3E. Reconnaissance of section 10 for this study failed to locate any additional veins or prospects. Hembrillo Canyon prospects consist of thin veins and small replacement bodies in limestone within a faulted block of Lead Camp Limestone (Seager, 1994). The deposit is less than 92m long and consists of galena, barite, quartz, calcite, iron oxides, and possibly trace wulfenite. A sample of the Lot OM-69 prospect reportedly contained 77.8 percent $BaSO_4$, 14.8 percent SiO_2, and 0.3 percent $CaCO_3$ (Williams and others, 1964). Samples collected for this report assayed 250-1,600 ppm Cu, 16,000-42,000 ppm Pb, <50-1,700 ppm Zn, 0.00-0.38 oz/short ton Ag, and no detectable gold.

Barite-fluorite-galena deposits in the San Andrecito-Hembrillo district are classified as Rio Grande Rift deposits by North and McLemore (1986). At the Green Crawford mine, veins have textures similar to those of epithermal-vein deposits, but there is no indication of nearby igneous intrusive activity. Therefore, veins at the Green Crawford Mine are classified as a variation of Rio Grande Rift deposits.

Prospect pits and a 5-m shaft occur in Hospital Canyon ($SW^1/_4$ sec. 18, T.16S., R.4E.) along quartz-calcite veins that cut Proterozoic amphibolite. Alteration consists of hematite and local sericite. Malachite is present on the dump.

Additional veins of copper and barite reportedly occur in the San Andrecito-Hembrillo district, but could not be located during this study. Kendrick copper prospect occurs on the east slope between San Andrecito Canyon and Deadman Canyon (Dunham, 1935). An adit was driven along a copper vein in Hospital Canyon (The Mining World, 4/23/10, p. 868).

Industrial minerals that occur in the Organ-San Andres Mountains within the study area include limestone deposits, but apparently none, with the exception of certain beds in the Lake Valley and Hueco sequences, are high-calcium limestones (Kottlowski, 1962). Most of the deposits are within the WSMR and off-limits to mining.

RINCON HILLS

Rincon District

Location, Mining History

Rincon district, also known as the Hatch and Woolfer Canyon districts, lies in the southern Caballo Mountains in northern Doña Ana County. It was discovered in the early 1900s. The district includes a large area of scattered barite and manganese deposits from north of the Doña Ana-Sierra County line southward to Rincon (**figure 5-4.12**). Production from the Rincon district amounts to 10,250 short tons of barite and 1,529 short tons of 27-40 percent Mn (Farnham, 1961; Dorr, 1965; Williams and others, 1964; Filsinger, 1988). Mineral production from mines and prospects are listed in **table 5-4.12**.

District Geology

Rincon district consists of Paleozoic rocks that were deformed during Laramide events (Seager and Hawley, 1973; Seager and Clemons, 1975). The rocks were overlain by less deformed Tertiary-Quaternary sedimentary and volcanic rocks. High-angle normal faults cut the rocks and have localized barite and manganese in vein and replacement deposits in limestone and volcanic rocks. Rhyolite dikes and sills intrude the rocks locally.

Mineral Deposits

Rio Grande Rift barite-fluorite deposits (see Sutphin, this volume) occur in the Fusselman Dolomite beneath the Percha Shale. The Palm Park deposit is the largest (**figure 5-4.13**), and consists of calcite, barite, fluorite, and trace amounts of malachite, azurite, pyrite, galena, chalcopyrite, sphalerite, covellite, and quartz (Filsinger, 1988). Assays are less than 0.02-0.11 percent Cu, 0.01-11.5 percent Pb, and 0-2.9 oz/short ton Ag (Filsinger, 1988). Brecciation, banded ore, and veins are common textures and jasperoid is common. Manganese and iron oxides are locally pervasive. Fluid inclusion temperatures range from 163˚C to 341˚C (barite, fluorite, quartz) and have moderate salinities (4.8-17.0 equiv. wt. percent NaCl), indicating formation by mixing of saline connate-meteoric waters with heated hydrothermal fluid possibly of magmatic

origin. Horseshoe and Prickly Pear deposits are smaller, but similar to the Palm Park deposit. A rhyolite sill intrudes the Paleozoic sedimentary rocks north of the Horseshoe deposit where jasperoid formed. In one locality, jasperoid contains rhyolite fragments (Filsinger, 1988). These relations suggest that the barite deposits are probably younger than the rhyolite sill, which is probably middle Tertiary in age. Stratigraphic relationships at the Morgan Mine suggest a Miocene age for the manganese deposit (Seager and Hawley, 1973); a similar age is likely for the barite deposits.

The drilled Palm Park deposit contains 1.5 million short tons of ore grading 27 percent $BaSO_4$ with a specific gravity of 3.07 (Filsinger, 1988). The Horseshoe deposit could contain as much as 50,000 short tons of 5-20 percent $BaSO_4$, but in deposits less than 1.5m thick. Prickly Pear deposit could contain as much as 200,000 short tons of 5-25 percent $BaSO_4$, but also in deposits less than 1.5m thick (Filsinger, 1988). These barite deposits are uneconomic at present and would be mined only if petroleum exploration increases the demand for barite in drilling muds. The whiteness and brightness of the barite is suitable for certain paints and fillers, and could be produced for these uses if nearby specialized markets were developed.

Epithermal manganese deposits are common in the Rincon district. Velarde (Blackie, Sheriff) Mine is the largest and consists of replacement, veins, and open-space fillings of manganese oxides, calcite, manganiferous calcite, iron oxides, quartz, and, local barite. Manganese oxides also form cement in breccias and sandstones. The deposits are hosted by dolomite and dolomitic limestone, Bat Cave and Cable Canyon sandstones, and Upham Dolomite. The area is characterized by elevated concentrations of Ba, Co, Mn, Ti, and local Cu, Pb, and Zn anomalies in stream-sediment samples (Hassemer and Marsh, unpublished data, 1995). These deposits are low-tonnage, low-grade, and uneconomical.

Travertine

White, pink, brown, and gray travertine is common in the Rincon district and surrounding areas. It occurs in the Palm Park Formation in the northern Rincon quadrangle (Seager and Hawley, 1973). Banded deposits are up to 1.8m thick (Barker and others, 1995). Many deposits are small, but can meet local needs as a decorative stone. Gypsiferous clay deposits occur in the Rincon Valley Formation near Rincon.

ROBLEDO MOUNTAINS

Iron Hill District

Location, Mining History

Iron Hill district, also known as the Robledo district, is located in the southwestern Robledo Mountains. The district was discovered in the early 1930s, but production is unknown.

Nearly two dozen pits, shafts, and adits occur in the area, exposing sedimentary iron deposits (see Sutphin, this volume; Dunham, 1935; Kelley, 1949; Harrer and Kelly, 1963). The Gilliland group of deposits occurs in sec. 2, T.22S., R.1W., and the Iron Hill deposits are in sec. 16, T.22S., R.1W. Robledo Mountains WSA lies north of the district (**figure 1-2**).

District Geology

Ordovician to Permian and Eocene sedimentary rocks are exposed in the Robledo Mountains and are overlain by Tertiary volcanic and sedimentary rocks and Quaternary deposits (Hawley and others, 1975). Iron deposits are hosted by limestone of the Hueco Group (F.E. Kottlowski, NMBMMR, oral commun., May 10, 1995). Rhyolite sills, dikes, and domes form the northern portion of the range and the Cedar Hills to the west (Hawley and others, 1975; Seager and Clemons, 1975). A large sill between Robledo Peak and Lookout Peak has been dated as 36Ma (unpublished data, NMBMMR). The district forms the northern part of a gravity high, which coincides with the Doña Ana Mountains caldera (Abrams and Klein, this volume).

Mineral Deposits

Iron Hill deposits consist predominantly of hematite, goethite, and limonite with local concentrations of manganese oxides, gypsum, calcite, quartz, and ocher (Dunham, 1935; Kelley, 1949). Deposits occur in lenticular replacement, breccia cement, and cavity filling deposits in limestone. Bodies, which both parallel and cut bedding, range from small replacement pods to 60m x 37 m-wide massive zones (Dunham, 1935). Ore is porous and banded, with botryoidal and stalactitic textures and common crustations (Kelley, 1949; Harrer and Kelly, 1963).

Their origin is speculative. Dunham (1935) suggests that the deposits were formed as a result of leaching of hematite cement from overlying Permian sedimentary rocks (Abo Formation tongue, Hueco Group) and precipitation into voids in the underlying middle Hueco limestone units. Kelley (1949) suggests that these deposits could have formed by percolation of surface, subsurface, or magmatic waters of varying temperature.

In 1949, Kelley (1949) estimated the indicated reserves at Iron Hill as 5,000 short tons and the inferred reserves as 15,000 short tons, both with a grade of 50-55 percent Fe. Despite these reserves, it is unlikely that these deposits will be mined in the near future owing to small tonnage, low grade, poor quality, and inaccessibility.

Travertine

Pink, orange, lavender, white, brown, and gold travertine occurs in the district along the Cedar Hills and other north-trending faults (Hawley and others, 1975; Clemons, 1976); some of the larger deposits are in sec. 23, 25; T.21S., R.1W. Banded travertine (sec. 25, T.21S., R.1W.), known locally as “Radium Springs marble" or "Radium Springs onyx”, occurs in veins

and as apron-like deposits. It is quarried for decorative stone. Rainbow pit (sec. 23, T.21S., R.1W.) currently produces 96 cu ft/day (Hatton and others, 1994); other pits occur in secs. 23, 26, 35; T.21S., R.2W. (Clemons, 1976).

Exposed Pennsylvanian strata are thick, locally high-calcium limestones. Hueco Group contains numerous thick limestone beds, but the extent of high-calcium types is unknown. The massive limestones of the Bursum Formation may be high-calcium (Kottlowski, 1962).

SAN DIEGO MOUNTAIN-TONUCO UPLIFT

Tonuco Mountain District

Location, Mining History

Tonuco Mountain mining district (also known as the San Diego Mountain district) is located on the east side of the Rio Grande southeast of Rincon, and consists of two small *en echelon* uplifts --the Tonuco and West Selden Hills uplifts (Seager and others, 1971). Rio Grande Rift fuorite-barite veins in Proterozoic rocks were discovered in 1900 (**table 5-4.13**) and from 1919 to 1935, 200 short tons of barite and 7,720 short tons of fluorite were produced (Rothrock and others, 1946; Clippinger, 1949; Williams and others, 1964; McAnulty, 1978). A fluorite mill was erected at the Tonuco Mine in 1922 (Ladoo, 1923).

District Geology

Proterozoic granite and sedimentary rocks of the Bliss Formation and El Paso Limestone are exposed in the Tonuco block. More than 2,440m of Tertiary volcanic and sedimentary rocks overlie Proterozoic and Paleozoic rocks (Seager and others, 1971). High-angle normal faults have uplifted the block.

Mineral Deposits

Fluorite-barite veins are typically small (less than 30 cm wide), discontinuous, and trend north and northwest. Stratigraphic relations indicate that the veins are probably Miocene (Seager and others, 1971); they occur along faults and fractures in Proterozoic rocks and as open-space fillings in the silicified Hayner Ranch Formation. Beal vein is several hundred meters long, less than 0.5m wide, strikes N.25˚W., and dips 70˚SW. Samples from the Beal claims assayed 21.4-38.7 percent CaF_2 and 28.1-49.2 percent $BaSO_4$ (unpublished data, NMBMMR). Tonuco vein is 300m long, less than 3m wide, strikes N.70˚W., and dips 60˚SW. A sample assayed 35.7 percent CaF_2 and 47.2 percent $BaSO_4$ (unpublished data, NMBMMR). Both veins consist of barite, quartz, calcite, iron and manganese oxides, and fluorite. The area is characterized by anomalous local concentrations of Co, La, Pb, Th, Ti, and Zn in stream-sediment samples (Hassemer and Marsh, unpublished data, 1995).

Travertine

Radioactive travertine occurs along the northwest base of San Diego Mountain (Boyd and Wolf, 1953; Seager and others, 1971; Seager, 1975) and was formed in Pleistocene time by springs (Barker, 1995). Travertine was quarried in the Buckle Bar area of Selden Hills ($SE^1/_4$ sec. 20, $SW^1/_4$ sec. 21, T.20S. R.1W.).; most is white. Many deposits are small, but would meet local needs for decorative stone.

TORTUGAS MOUNTAIN

Tortugas Mountain District

Location, Mining History

Tortugas Mountain, also known as "A" Mountain, is located east of Las Cruces in secs. 23, 24, T.23S., R.2E. Tortugas Mountain mining district was discovered in 1900. Rio Grande Rift deposits of barite, fluorite, and manganese occur along faults in Permian units containing limestone and dolomite (Dunham, 1935; McAnulty, 1978; Macer, 1978; King and Kelley, 1980). From 1919-1943, 20,751 short tons of fluorite and 100 short tons of barite were produced (Williams and others 1964; McAnulty, 1978). Numerous adits, shafts, and pits developed the veins for a strike length of 366m and a depth of 87m (Dunham, 1935). The New Mexico Abandoned Mine Lands Bureau reclaimed the area in 1990 and the deposits are now inaccessible. At least eight holes have been drilled south and east of Tortugas Mountain for geothermal resources (Gross and Icerman, 1983) (see Duffield and Priest, this volume).

District Geology

Tortugas Mountain is a west-tilting horst block consisting of silicified and dolomitized Permian limestone and shale and Tertiary to Recent unconsolidated sedimentary rocks (King and Kelley, 1980). North-northwest- and north-trending normal faults cut and offset Permian rocks. Many faults are mineralized and silicified (King and Kelley, 1980). Approximately 610m of limestone underlies Tortugas Mountain (Gross and Icerman, 1983).

Mineral Deposits

Numerous faults and fracture zones in the Tortugas Mountains are mineralized by fluorite-calcite veins. The largest fluorite-calcite vein (up to 3m thick) occurs along the Tortugas fault and has been mined to a depth of 162m (Rothrock and others, 1946; King and Kelley, 1980). Ore averaged 77.4 percent CaF_2, 15.68 percent $CaCO_3$, and 6.51 percent SiO_2 (Ladoo, 1927). Fluid inclusion analyses indicate formation temperatures of 180˚C-191˚C (temperatures of homogenization) and low salinities (less than 2 equiv. wt. percent NaCl) (Macer, 1978; North and Tuff, 1986), probably by meteoric hydrothermal fluids. It is unlikely that ore remaining in the

underground pillars at the Tortugas Mine would be of sufficient tonnage to be produced under current economic conditions (G.B. Griswold, unpublished report, December 1980; unpublished data, NMBMMR). Tortugas Mountain is characterized by anomalous local concentrations of Co, La, Mn, Mo, Pb, Th, and U in stream-sediment samples (Hassemer and Marsh, unpublished data, 1995).

Travertine

A small travertine deposit occurs on the northern part of the mountain (secs. 23, 24, T.2E., R.23S.). The deposit is white and gray, and probably suitable only for local use.

QUANTITATIVE MINERAL-RESOURCE ASSESSMENT --ESTIMATE OF UNDISCOVERED MINERAL RESOURCES

by

David M. Sutphin, Virginia T. McLemore, Gerda A. Abrams, Susan Bartsch-Winkler, Jerry R. Hassemer, Douglas P. Klein, James A. Pitkin, Miles L. Silberman, and Alan R. Wallace

INTRODUCTION

At the request of the BLM, the USGS is providing subjective probabilistic estimates for the existence and number of undiscovered mineral deposits within the Mimbres Resource Area. Assessment is possible, given the current available information, for numerous deposit types. Other deposit types are known to occur, or have potential for occurrence, within the study area, but could not be evaluated quantitatively, because critical data needed for the estimation process are not currently available. Results of the assessment are provided for use by the BLM in land-use planning and minerals-potential supply analysis in anticipation of any conceivable development of mineral deposits that might be discovered in the study area.

METHODS OF MINERAL-RESOURCE ASSESSMENT

Characteristics of the mineral occurrences described elsewhere in this volume were examined, and the occurrences were assigned to the mineral deposit model best representing those characteristics. In this section, probabilistic estimates are calculated for the quantity of mineral resources in undiscovered mineral deposits in the study area, based partly on the expert judgment of a number of geoscientists familiar with the geology of the area and with the geology of mineral deposits and their characteristics. A one-kilometer depth for minable mineral deposits was set as the economic limit for viable mining activities today and in the near future.

Requirements for the multistage assessment process can be divided into two broad categories: (1) acquisition of regional geologic information; and (2) integration of this information into the assessment. Regional information required to assess the study area includes (1) a regional geologic map that emphasizes lithologic units and ages at the same or smaller scale than that of the assessment (**plate 1**); and (2) an inventory of known mineral deposits, prospects, and occurrences in the region. The geologic map is the primary tool used to delineate the various types of tracts (non-permissive, permissive, and favorable). Mineral deposits, prospects, and occurrences are not always completely described, especially in older literature (pre-1950), wherein the rock and mineral-deposit terminology and genetic concepts differ from present-day usage. Reinterpretation for contemporary deposit-type identification was necessary. Mineral occurrences and prospects are important indicators of deposit type, and place geographic and geologic limitations on the

possibility of occurrence in any given region. Field examination of numerous deposits was accomplished by members of the resource assessment team, with the aim of clarifying some of the unknown occurrences.

Geophysical information, particularly aeromagnetic and gravity data, may indicate anomalous or mineralized areas or extensions of mineralized areas. Geophysical information is best utilized to identify rock units under covered areas. Both stream-sediment and rock geochemistry furnish similar benefits to large regions, providing direct surficial evidence for the presence of elements or suites of elements associated with the processes of mineralization. Preliminary geochemical maps and data sets complete at the time of the assessment were examined, but final maps and data sets were not finished for inclusion in this report. Information about the extent and efficiency of past exploration in the region can be useful for a regional resource assessment, but it is often difficult to obtain and evaluate. Integration of all the information into a resource assessment is diagrammed in **figure 6-1**.

The technique used here to estimate the undiscovered mineral resources is based on the three-step quantitative assessment described in Singer (1993), Menzie and Singer (1990), Singer and Cox (1988), and Singer and Ovenshine (1979). The steps are: (1) using known geological, geochemical, and geophysical characteristics, delineate tracts that may contain specific deposit types; (2) estimate the probabilities that a certain number of undiscovered deposits exists in these tracts; and (3) estimate the amount of a given commodity contained in the undiscovered deposits by means of comparison with the grades and tonnages of known deposits of a similar type. **Figure 6-2** shows how the three steps are integrated into a quantitative mineral-resource assessment. These individual steps can be done independently. Steps (1) and (2) are conducted by a team of specialists; step (3) is a computer simulation. Deposit models provide a format for the integration of the information in the region being assessed.

In the Mimbres Resource Area, estimates of the numbers of undiscovered deposits were made for several types of metallic and nonmetallic mineral deposits having grade and tonnage mineral deposit models. The estimates were made by a team of geoscientists (the "assessment team"), consisting of specialists in economic geology, geochemistry, geophysics, and mineral-resource assessment who studied the area and who briefly visited and sampled many locations in the area. These specialists included Gerda A. Abrams, Susan Bartsch-Winkler, Jerry R. Hassemer, Douglas P. Klein, James A. Pitkin, Miles L. Silberman, David M. Sutphin, Alan R. Wallace of the U.S. Geological Survey (USGS) and, Virginia T. McLemore of the New Mexico Bureau of Mines and Mineral Resources (NMBMMR). William A. Scott (USGS) conducted the computer simulations.

Tracts permissive and favorable for the occurrence of undiscovered mineral resources in the Mimbres Resource Area were delineated from the geological, geochemical, and geophysical data available for the area. Geological information was used initially to select areas (or tracts) of favorable rock types and to interpret the structure of the surface and subsurface. Locations of the mining districts (**figure 1-12**) were important in recognizing areas of known mineralization. Geochemical data revealed areas of anomalous values for metals in deposits, such as silver and copper, or pathfinder elements, such as antimony, arsenic, and mercury. Preliminary maps of geochemical data were used to reduce or expand the areas initially, based on the geological information, and to detect target areas that might have been overlooked previously. Geophysical maps and seismic data were used to estimate the distribution of rock types in the subsurface. Remote sensing and aeroradiometric surveys enabled detection of additional anomalies on the surface. Geological, geochemical, and geophysical data from the study area were compared to the geological settings and characteristics of the existing deposit types; finally, a consensus on the tract borders was met by the assessment team.

After selecting appropriate deposit models and delineating permissive tracts and areas favorable for them, an estimate of the number of undiscovered deposits was made. The method for estimating the number of undiscovered mineral deposits is subjective and relies on the expert judgment of a number of geoscientists familiar with the data. A consensus on the types of deposits permissive in each tract, and the number of deposits using 90, 50, 10, 5, 1, 0.5, and 0.1 percent probability levels, was reached after further discussion.

A computer simulation program used to transform estimates of the number of undiscovered deposits into estimates of contained commodities in those deposits is known in the U.S. Geological Survey as "MARK-3" (Drew and others, 1986; Root and Scott, 1988; and Root and others, 1992). The program requires estimates of the number of undiscovered deposits of a given type within an area. The number of deposits is stated in terms of likelihood of occurrence, resulting in a probability distribution. Computer simulations are performed by selecting simulated deposits from this probability distribution, and for each simulated deposit, selecting a grade and tonnage according to probability distributions of the grades and tonnages of known deposits of a given type. Undiscovered mineral deposits estimated for each deposit type have the same grade and tonnage distribution as the worldwide distribution for that deposit type. That is, half of the undiscovered deposits would be larger and half smaller than the median for that deposit type. Grade and tonnage models (**table 6-1**; **figure 6-3**) used in this report are, with few exceptions, taken from compilations of mineral deposit models such as Cox and Singer (1986), Bliss (1992), and Orris and Bliss (1992). Grades and tonnages of the simulated deposits are accumulated as part

of the simulation process. Once the simulations are performed, the program generates the probability distribution of the contained commodities in the simulated deposits that correspond to the initial estimates of the numbers and types of deposits. These results are presented in an attempt to bridge the gap between a qualitative assessment of the study area's favorability for mineral-deposit occurrence and a quantitative inventory of its mineral resources and do not explicitly consider the economic processes of exploration, development, production, processing, and marketing necessary to transform a mineral resource into a material product.

MINERAL-RESOURCE TRACTS

Permissive tracts, nonpermissive tracts, and favorable areas were determined for mineral deposit types occurring in, or having a probability of occurring in, the Mimbres Resource Area. Permissive tracts are areas drawn for one or more deposit types, such that the probability of a deposit lying outside the boundary are negligible --on the order of 1:100,000 or 1:1,000,000 (Singer, 1993). They are delineated as the widest probable area having, or suspected of having, conditions permissive for the formation of ore deposits of the types being considered. Nonpermissive tracts for undiscovered deposits are those with a probability of occurrence of less than about 1:1,000,000.

Favorable areas are subsets of permissive tracts and are delineated on the basis of geology, exploration history, and geophysical and geochemical information. In the following discussions, permissive tracts and favorable areas are delineated and the criteria are given that suggest that undiscovered mineral deposit types occur in each area. For each of these deposit types, descriptive and grade and tonnage models are displayed; from these graphical displays, undiscovered resources can be extrapolated.

Permissive tracts and favorable areas are delineated for porphyry deposits, carbonate-hosted deposits, skarn deposits, metallic vein deposits, volcanogenic massive sulfide deposits, epithermal vein deposits, or other types of deposits. Estimates of undiscovered resources are given only to two significant digits (hundredths). A greater degree of accuracy (more digits) may imply precision beyond the present capability of the deposit models, estimates of undiscovered deposits, and computer simulations.

FAVORABLE AREAS, AND PERMISSIVE AND NONPERMISSIVE TRACTS FOR SELECTED MINERAL DEPOSIT TYPES

PORPHYRY DEPOSITS

Porphyry deposits include porphyry copper, porphyry copper skarn-related, porphyry copper-molybdenum, and porphyry molybdenum, low fluorine deposits. These deposits form in similar settings and under similar conditions. **Plate 2** shows that much of the study area is permissive for the occurrence of porphyry deposits. One large permissive tract covers the study area; favorable areas generally cover mining districts and surrounding terrane. Parts of the study area are nonpermissive for the occurrence of porphyry deposits.

The permissive tract was defined as follows: (1) areas where rocks of Tertiary age or older are within one km of the present surface; (2) areas having volcanic and intrusive rocks of Late Cretaceous and Tertiary age and where geophysical anomalies indicate the presence of buried intrusions, which could provide thermal energy, pressure, and hydrothermal fluids to create a mineralized porphyry system; (3) areas of reported densely spaced faults and fractures, areas of argillic and propylitic alteration, and (4) areas of known porphyry mineral occurrences, prospects, and deposits, as well as mining districts having skarn, vein, and replacement deposits that may be associated with porphyry mineralization. Evaluations from previous assessments, such as the assessment of the Douglas (Hammarstrom and others, 1988), Silver City (Richter and others, 1984), and Van Horn and El Paso (Johnson and others, 1988) 1˚ x 2˚ quadrangles, were used to help delineate these tracts. Geochemical anomalies for base metals, precious metals, and pathfinder elements were useful in refining the boundaries for the permissive tract.

Areas outside of the permissive tract (nonpermissive tracts) lack criteria making them permissive for the presence of porphyry deposits within one km of the present surface, based on geologic, drill-hole, gravity, and seismic information. Such areas are in basins occupied by thick sequences of alluvial and fluvial fill, have no gravity or magnetic anomalies indicative of near-surface intrusions allowing porphyry mineralization, and lack geochemical anomalies in stream-sediment samples, or have anomalies that are rare, scattered, or sufficiently distal from source rocks as to be ambiguous.

Eleven tracts in the area are not permissive for the occurrence of porphyry deposits, because they lack characteristics compatible with formation of these deposits. Each nonpermissive tract, such as in Jornado del Muerto north of the Doña Ana Mountains and part of Mimbres River Valley between Deming and Faywood, are in modern basins that probably contain valley fill greater than one km thick. Also, geophysical surveys show no gravity or magnetic anomalies suggesting the presence of buried intrusives. Where available, seismic data verified that the basins

lacked bedrock within one km depth. In general, nonpermissive tracts for porphyry deposits have almost none of the criteria needed for the occurrence of porphyry deposits, and the team determined that exploration in those areas would have a 1: 100,000 to 1: 1,000,000 chance of successfully locating a porphyry deposit.

Estimates of deposits for the permissive areas were made by aggregating separate estimates for favorable tracts within the permissive area. Favorable areas for porphyry deposits were delineated using all of the information that the assessment team had available. Locations of the known mineral deposits and mining districts played an important role in determining the location of favorable areas, as did the presence of gravity, magnetic, and geochemical anomalies. Positive gravity and magnetic anomalies were interpreted as indicative of subsurface intrusives, and a place where a porphyry system could have developed. Negative magnetic anomalies in the presence of a gravity high were interpreted as indicating an area where possible hydrothermal alteration may have removed the remanent magnetism from the rocks --a positive indicator for porphyry mineralization. Gravity and seismic data were used also to locate certain shallow bedrock types capable of hosting porphyry deposits.

Geochemical anomalies for precious- and base-metal elements and their accessories are important criteria for delineating favorable areas. Coupled with geophysical anomalies, geochemical anomalies provide necessary evidence of mineralization proximal to a suspected intrusion. The occurrence of a mining district and/or mineral deposits in association with a geophysical anomaly and/or surrounding geochemical anomalies suggest that much of the area included in the geophysical anomaly outside of the mining district is favorable for the occurrence of undiscovered porphyry deposits. Additionally, in the Lordsburg Mesa area where there is no known mineralization, the presence of documented alteration (Raines and others, 1985) and aeroradiometric K, U, and Th anomalies is used to delineate that favorable area. Each favorable area for the occurrence of porphyry deposits is discussed below.

Using the geological, geophysical, and geochemical information available and information on the mineral occurrences in the study area and adjacent to it, the assessment team estimated the numbers of undiscovered deposits of porphyry copper-molybdenum, and porphyry molybdenum, low fluorine deposits in the favorable areas at the 90, 50, 10, 5, and one percent confidence levels (**table 6-2**). Although porphyry deposits are permissive in other parts of the study area, those parts of the study area have a less than one percent chance of having an undiscovered porphyry deposit. The porphyry copper-molybdenum deposit model was used to represent all porphyry copper deposit types, since determination of the porphyry type was deemed beyond the resolution of available data. The porphyry copper-molybdenum deposit model was selected as best

representing the porphyry copper deposits yet to be discovered in the study area; estimates of undiscovered deposits and subsequent computer simulations were made using that model. Likewise, the porphyry molybdenum, low fluorine deposits model was deemed the best to represent undiscovered molybdenum deposits in the area. Results of the computer simulation and the expected means of metal tonnages in undiscovered porphyry deposits are shown in **table 6-3** Expected mean tonnages of metals in undiscovered porphyry.

Areas Favorable for Porphyry Deposits

Alum Mountain Favorable Area

Delineation of this area as favorable for the occurrence of porphyry copper-molybdenum deposits is based primarily upon the presence of a large zone of acid-sulfate alteration (McLemore, 1995; interpreted as supergene by Ratté and others, 1979) and the location of the Alum Mountain mining district associated with the alteration zone. Presence of a magnetic high south of the district and a magnetic low to the west were additional evidence. If the assumption is accurate that the magnetic highs in the Santa Rita area are associated with intrusions and porphyry mineralization, the same may be true in this area.

Geochemical stream-sediment anomalies for Be, Co, Cr, Cu, Mn, Mo, Nb, Pb, Th, Ti, and Y may be indicative of buried mineralization. The boundary of the area is defined primarily by the surficial location of alteration. Geophysical data confirmed the location of the alteration zone in the form of an aeroradiometric K high. An aeroradiometric U high on the east side of the area and an offset Th low may be additional indicators of hydrothermal alteration. The area is situated along the south edge of the Gila caldera where abundant fracturing and faulting may have formed conduits through which hydrothermal fluids could have had easy access to the volcanic rocks. One concern of the team was that a suspected porphyry deposit could be buried at a depth greater than the one-km limit of this study.

Given the evidence, the assessment team estimated a one percent probability of 2 undiscovered porphyry copper-molybdenum deposits. Computer simulation using MARK-3 and the team estimates shows that the mean number of deposits expected is 0.0552. There is a 96 percent probability of finding no undiscovered porphyry copper-molybdenum deposits, and 2 percent probabilities of finding both one deposit or two or more deposits. Expected mean of tonnages of copper and molybdenum are 270,000 tonnes and 7,500 tonnes, respectively. Expected mean of tonnages of silver and gold are 81 tonnes and 0.88 tonnes, respectively. Expected mean tonnage of mineralized material is 52 million tonnes.

Apache Favorable Area

Apache favorable area includes the Apache No. 2 and Fremont mining districts and is one of the areas suspected to have porphyry mineralization. The area was selected as being favorable for the occurrence of porphyry copper-molybdenum mineralization on geological, geophysical, and geochemical evidence.

Geologically, the area contains much of the Apache Hills caldera, a mid-Tertiary caldera that may have provided magmatic fluids and created fractures that could have formed a porphyry system. The area lies on a northwest-trend parallel to the Texas lineament. Geophysical evidence consists of a distinct aeroradiometric anomaly (high U, low Th, low K) indicative of the presence of carbonate rocks proximal to the caldera. A local gravity high and regional magnetic high cover most of the area. Stream-sediment anomalies of As, Be, Bi, Cd, Co, Cu, K, La, Mo, Pb, Sb, Th, U, Y, and Zn are also indicative.

Using this evidence, the team estimated a 10 percent probability that the area would contain one undiscovered porphyry copper-molybdenum deposit, a 5 percent probability of 2 deposits, and a one percent probability of 3 or more deposits. Results of the computer simulation show a 70 percent probability that no undiscovered porphyry copper-molybdenum deposits are located in the area. There is, however, a 22.5 percent probability of one undiscovered deposit, a 4.5 percent probability of 2 deposits, and a 3 percent probability of 3 or more deposits. The mean number of undiscovered porphyry copper-molybdenum deposits that can be expected is 0.3891. Expected mean metal tonnages are 1.9 million tonnes Cu, 56,000 tonnes Mo, 630 tonnes Ag, and 7.2 tonnes Au, contained in 390 million tonnes of mineralized material.

Gila Fluorspar Favorable Area

Delineation of the Gila Fluorspar favorable area is based on the geology of the area supported by geochemical and geophysical data. The area includes Gila Fluorspar mining district and the zone of advanced-argillic alteration within the district (Ratté and others, 1979; McOwens, 1994; and McLemore, 1995). The northern boundary is south of Bursum caldera, but some of the fractures that run parallel to the caldera ring-fracture zone are within the area. The caldera is mid-Tertiary in age, the age of many of the porphyry deposits in the region. A magnetic high is located south of the mining district, and a gravity high covers most of the area, extending to the south. There is an aeroradiometric U high within the area, and an offset Th low. Geochemical stream-sediment anomalies of Ag, Ba, Co, Cu, Mn, Mo, Nb, Pb, and Zn may be indicative of undiscovered mineralization.

Gila Fluorspar favorable area was not assessed as likely for undiscovered porphyry deposits, because a suspected deposit may be deeper than the one-km limit. Using available

geological, geochemical, and geophysical evidence, the team estimated that there is a one percent probability of one or more undiscovered porphyry copper-molybdenum deposits. Results of the MARK-3 computer simulation show a 97 percent probability of no undiscovered porphyry copper-molybdenum deposits and a 3 percent probability of one or more deposits. The mean number of deposits expected is 0.0324. Expected means of metal tonnages are 130,000 tonnes Cu, 3,900 tonnes Mo, 39 tonnes Ag, and 0.43 tonnes Au contained in 26 million tonnes of mineralized material.

Little Hatchet Favorable Area

Little Hatchet favorable area includes the Eureka and Sylvanite mining districts in the Little Hatchet Mountains. In both districts, porphyry mineralization is suspect, but none has been discovered. Gravity and geomagnetic data were used to help define the boundary. Partially distinct magnetic highs occur on the west side of Eureka district, beneath Sylvanite district, and to the south of that district in the southern part of the area. This southern magnetic high also exhibits K, U, and Th aeroradiometric highs. Over each magnetic high, a distinctive aeroradiometric anomaly (high U, low Th, low K) is indicative of carbonate rocks, and the southwestern boundary of the area is defined by aeroradiometric K and Th anomalies, and slightly elevated U levels. Geochemical anomalies for several elements were noted. In Eureka district, anomalies of As, Cd, and Co were reported; Mn is anomalous at the north end of the district, and Pb, Sb, and Zn are localized. Sylvanite district is anomalous in As, Cd, Co, Cu, Mn, and Mo, with local occurrences of Sb; the south end of the district is anomalous in Be, Bi, K, La, Nb, Th, U, and Y. Sylvanite district is characterized by gold placers, and precious- and base-metal skarn deposits.

Based on geological, geochemical, and geophysical evidence, the assessment team estimated a 5 percent probability of one undiscovered porphyry copper-molybdenum deposit and a one percent probability of 2 or more such deposits. **Table 6-3** shows the results of the computer simulation. Using the estimates, the computer determined that there is a 92.5 percent probability of no undiscovered porphyry copper-molybdenum deposits, a 4.5 percent probability of one deposit and a 3 percent probability of 2 or more deposits. The mean number of deposits expected is 0.0988. The expected mean metal tonnages are 460,000 tonnes Cu, 14,000 tonnes Mo, 130 tonnes Ag, and 1.5 tonnes Au contained in 94 million tonnes of mineralized material.

Lordsburg Favorable Area

Designation of the Lordsburg area as favorable for the occurrence of undiscovered porphyry mineral deposits is based on geological, geochemical, and geophysical evidence. The area includes Lordsburg mining district where numerous base-metal veins, which have produced large amounts of metals in the past, have been discovered. Pronounced E- to ENE-trending faults

and dikes are present in the area. The presence of a Tertiary quartz monzonite porphyry and associated propylitic alteration is conducive for the occurrence of porphyry mineralization. Despite the occurrence of altered rocks, distinctive porphyry alteration zones are missing. Gravity and magnetic highs, indicative of a thick accumulation of andesites or other volcanic rocks, and an aeroradiometric K anomaly are present. Rhyolite plugs were recently explored for mineralization by drilling. Locally anomalous amounts of Ag, Ba, Cu, Mn, Pb, Ti, and Zn, ± Be, Mo, and Sn were noted in stream-sediment samples. Richter and others (1986) determined that the west side of the Lordsburg area was favorable for the occurrence of Safford-type porphyry copper deposits. Based on favorable lithologies, alteration, and geophysical information, the assessment team delineated a larger area.

Using available information, estimates were made for both porphyry copper-molybdenum and porphyry molybdenum, low fluorine deposits. The assessment team determined a 10 percent probability of 2 undiscovered porphyry copper-molybdenum deposits, a 5 percent probability of 3 or more undiscovered porphyry copper-molybdenum deposit, and one porphyry molybdenum, low fluorine deposit; and a one percent probability of 3 or more porphyry copper-molybdenum deposits and one or more porphyry molybdenum, low fluorine deposits. Results of the computer simulation are show in **table 6-3**. Computer simulations show a 60 percent probability of no undiscovered porphyry copper-molybdenum deposits, a 20 percent probability of one deposit, a 12.5 percent probability of 2 deposits, and a 7.5 percent probability of 3 or more deposits. The mean number of such deposits is 0.6755. Expected mean metal tonnages are 3.6 million tonnes Cu, 92,000 tonnes Mo, 1,100 tonnes Ag, and 12 tonnes Au, contained in 690 million tonnes of mineralized material. As for undiscovered porphyry molybdenum, low fluorine deposits in the Lordsburg favorable area, computer simulations determined a 92.5 percent probability of no such deposits and an 7.5 percent probability of one or more undiscovered deposits. The mean number of expected deposits is 0.0714. Expected mean molybdenum tonnage is 11,000 tonnes Mo contained in 15 million tonnes of mineralized material.

Lordsburg Mesa Favorable Area

Interest in the Lordsburg Mesa favorable area increased when Raines and others (1985) reported an area of limonitic alteration identified in Landsat imagery, which they correlated to a U anomaly. It was speculated that this was an area of possible calcrete uranium mineralization. In this report, the favorable area is defined almost solely using geophysical information and the presence of the alteration anomaly. The area lies on the gravity and magnetic ridge that extends into the Lordsburg area to the south. An aeroradiometric K high is present peripheral to the alteration zone, owing to erosion and transportation of the material. A magnetic high is located to

the northwest of the area. Geochemical anomalies for Ag, spot Cu, spot Mo, and Zn are speculative, since the stream-sediment samples were taken in alluvium, which has a wide source area.

Because the information on the area was based almost solely on geophysical data, including remote sensing data, and not on exposure, the assessment team felt that the favorable area had only a one percent probability of having one or more undiscovered porphyry copper-molybdenum deposits within one km of the surface. Computer simulation using the team estimate (**table 6-3**) determined a 97 percent probability of no undiscovered porphyry copper-molybdenum deposits and a 3 percent probability of one or more deposits. The mean number of such deposits is 0.0300. Expected mean tonnages of metals in these undiscovered deposits are 200,000 tonnes Cu, 5,500 tonnes Mo, 51 tonnes Ag, and 0.66 tonnes Au, contained in 36 million tonnes of mineralized material.

Organ Mountains Favorable Area

Organ Mountains favorable area extends from north of the Organ mining district to Bishop Cap and the northern Franklin Mountains. The boundary of the area is defined by surficial exposure of pre-Quaternary rocks, the occurrence of known mineral deposits including evidence of a porphyry copper deposit north of the village of Organ, and delineation of a steep gravity anomaly on the east and northwest boundaries of the area. In the Organ Mountains, mineral deposits are common, but deposits are fewer in number in the southern part of the area. Disseminated pyrite occurs locally in the Organ pluton; argillic alteration is pervasive. An intrusion (another porphyry target), which extends as far south as Organ Peak, is associated with a gravity low. Sericitic alteration may cause the gravity low in the Organ pluton.

Distinct aeroradiometric U/K and U/Th relative highs and gravity and magnetic highs, that cannot be explained using surface geology, suggest a series of intrusions at depth near Bishop Cap. The area would have potential for skarn mineralization if the deposits are shallow (less than one km deep). On the east side of the Organ Mountains from Bear Canyon to the Organ mining district, coincident Be, Cu, Mn, Mo, Pb, and Zn anomalies are present. La is anomalous on the east side of the area near Organ; Sb is anomalous in the Organ district. Nb and Ti are anomalous on the southern edge of the district, and Th is anomalous along the southern boundary, extending to the San Andres Mountains. Bishop Cap area is not considered promising for mineralization, owing to a lack of base-metal geochemical anomalies.

Organ Mountains favorable area is one of 2 areas considered to have a 90 percent probability of one porphyry copper-molybdenum deposit and a 10 percent probability of 2 or more deposits. Results of the computer simulation reflect the optimistic estimate (**table 6-3**). Analyses

indicate a 6.7 percent chance that no undiscovered porphyry copper-molybdenum deposits exist, a 63.3 percent probability of one deposit, and a 30 percent probability of 2 or more such deposits. The mean number of such undiscovered deposits is 1.2408. Expected means of metal tonnages in the undiscovered deposits is 6.4 million tonnes Cu, 170,000 tonnes Mo, 1,900 tonnes Ag, and 22 tonnes Au, contained in 1.2 billion tonnes of mineralized material. The expected tonnages reflect the high probability of occurrence of this deposit type.

Peloncillo Favorable Area

Peloncillo favorable area includes Granite Gap, McGhee Peak, and Kimball mining districts, sites of substantial past mineral production from carbonate-hosted and volcanic epithermal vein deposits. Alteration characterizes the area. The area boundary is defined chiefly by the geology and the extent of a large zone of hydrothermal alteration. The area lies on an elongate gravity high and magnetic low that may have been caused by hydrothermal alteration of the country rocks and removal of their constituent remanent magnetism. A magnetic high occurs to the east. Aeroradioactivity indicates that the area is within a region of relatively higher K and U. Geochemical anomalies for Ag, Cu, La, Pb, Sn, and spot Mn and La have been identified.

In the late 1970s, St. Joseph Mineral Co. drilled at least three diamond-drill holes in the western part of McGhee Peak mining district that intersected a porphyry between 1,360 and 2,000 ft depth. In 1994, a hole was drilled at the Charles mine in northern McGhee Peak district near Steins Pass, with a total depth of 1,460 ft. This hole did not intersect porphyry, but bottomed in intensely propylitized andesite with disseminated pyrite and thin pyritic veins (M.L. Silberman, USGS, written commun., March 3, 1995). A 1,400 ft deep hole was drilled in pyritic altered andesites in this area and bottomed in intensely altered pyrite-rich andesites (Silberman, oral commun. March 3, 1995). Silberman suggests that the most favorable part of the area includes the northern half of the McGhee Peak mining district, which is underlain by altered andesites.

The assessment team considered this the most favorable area for porphyry deposits in the study area. It was estimated that there is a 90 percent probability that one undiscovered porphyry copper-molybdenum deposit could occur, and a 50 percent probability for 2 or more of these undiscovered deposits. Results of the computer simulation are shown in **table 6-3**. Computer simulation shows a 6.7 percent probability of no undiscovered porphyry copper-molybdenum deposits, a 23.3 percent probability of one undiscovered deposit, and a 70 percent probability of 2 or more deposits. The mean number of expected undiscovered deposits is 1.6343. Expected mean metal tonnages are 8.5 million tonnes Cu, 230,000 tonnes Mo, 2,600 tonnes Ag, and 30 tonnes Au, in 1.7 billion tonnes of mineralized material.

Piños Altos-Santa Rita Favorable Area

Piños Altos-Santa Rita favorable area includes all or part of some of the most prolific past mineral producing mining districts in the study area, including Bayard, Fierro-Hanover, Georgetown, Piños Altos, and Santa Rita. In delineating this favorable area, it was observed that the known porphyry deposits occur on the flanks of magnetic highs. Thus, the area incorporates the flanks of three magnetic highs where porphyry deposits may occur. Aeroradiometric K and U highs are located at the edges of magnetic highs; however, magnetic highs are not pervasive in the area. Gravity data partially constrains the area boundary near Piños Altos, but by recognizing geochemical anomalies, the boundary was extended beyond the geophysical indications. The area includes the known porphyry copper deposit at Santa Rita.

Alteration is potassic and phyllic; pyritization and base-metal veins are widespread. Known calc-alkaline intrusive rocks are scattered throughout the area. One stock occurs at the junction of the Santa Rita northeasterly trend with another less pronounced NNW-trending fracture (Richter and others, 1986). Similar, buried intrusive rock at shallow depth could include mineralized porphyry systems similar to those discovered.

Richter and others (1986) found that anomalous Ag, Be, Bi, Cu, F, Mo, Nb, Pb, V, and W in the nonmagnetic fraction of concentrate samples were one indicator of possible porphyry mineralization. Metal anomalies (especially Cu in stream-sediment samples) are strong indicators.

It is possible that the geology extends in the subsurface across Mangas Valley graben, from the Tyrone-White Signal favorable area. From geophysical evidence, it appears that structures that control mineralization may connect across the graben. A drill hole located between the Tyrone and Santa Rita districts encountered volcanic rocks at 460 ft depth, and four of the drill holes between the 2 porphyry copper deposits indicate that graben fill is less than one km deep (Drewes and others, 1985).

Despite the occurrence of known porphyry deposits, the assessment team estimated a 50 percent probability of one or more undiscovered porphyry copper-molybdenum deposits. In addition, estimates show a 10 percent probability of 3 or more deposits. Results of the computer simulation are shown in **table 6-3**. Using the team's estimates, computer simulations determined a 30 percent probability of no undiscovered porphyry copper-molybdenum deposits, a 30 percent probability of one undiscovered deposit, a 20 percent of 2 deposits, and a 20 percent probability of 3 or more deposits. The mean number of undiscovered porphyry copper-molybdenum deposits is 1.2699. Expected mean tonnages are 6.6 million tonnes Cu, 170,00 tonnes Mo, 2,000 tonnes Ag, and 22 tonnes Au, contained in 1.3 billion tonnes of mineralized material.

Silvertip Favorable Area

Silvertip favorable area was determined on the basis of geological, geochemical, and geophysical evidence. The area lies within the Geronimo Trail caldera and contains the Silvertip mining district, where volcanic epithermal mineral deposits have been identified. Regionally, the area is in a zone of argillic alteration, and locally, advanced-argillic alteration is common (Hayes and others, 1982). The southern boundary is the extent of the most intense alteration; the northern boundary coincides with the caldera boundary. The area lies on a gravity gradient interpreted as a fault zone along the caldera boundary; a magnetic high marks an intrusion into the caldera wall. Aeroradiometric anomalies show U and Th highs along the caldera wall, where a geochemical anomaly of Nb is present. Other geochemical anomalies identified include Ba, Be, Bi, Cu, La, Mn, Mo, Sn, U, Zn, Co on the southeast, and Th on the north and east. Parts of the area were considered by Hayes and others (1982) as favorable for the occurrence of mineral deposits.

Despite a lack of significant mineral deposits in the Silvertip mining district, the assessment team estimated a one percent probability of one or more undiscovered porphyry copper-molybdenum deposits based on the favorable geology, numerous geochemical anomalies of economic and pathfinder elements, and geophysical anomalies that signal the edge of a caldera. MARK-3 computer simulation using the team's estimate determined a 97 percent probability of no undiscovered porphyry copper-molybdenum deposits, and a 3 percent probability of one or more deposits (**table 6-3**). The mean number of undiscovered porphyry copper-molybdenum deposits is 0.0268. Expected mean tonnages of metals in such deposits are 140,000 tonnes Cu, 3,800 tonnes Mo, 36 tonnes Ag, and 0.55 tonnes Au, contained in 28 million tonnes of mineralized material.

Steeple Rock Favorable Area

Steeple Rock favorable area includes the region of Steeple Rock mining district. Rocks in the area are mid-Tertiary in age and are favorable for the occurrence of a porphyry system. The area boundary is defined by structures, lithologies, and extent of known alteration. The area is on the north gradient of a NW-trending gravity high, lies in an area of low magnetic data, and is within an area having an aeroradiometric K high. The data may be indicative of epithermal alteration and faulting. Magmatic hydrothermal acid-sulfate alteration is pervasive (McLemore, 1993). Raines and others (1985) describe limonitic alteration in the area. Geochemical anomalies for Ag, Ba, spot Be, Co, Cr (northern and southern parts), Cu, K (northern part), La, Mn, Mo, Nb, Pb, spot Sn, Th, Ti (northern part), Y, and Zn have been identified using stream-sediment samples. Exploratory diamond drilling indicates a suspected porphyry at greater than 2,000 ft depth. Drilling at depths of approximately 1,500 ft around the Norman King and Billali mines

located disseminated chalcopyrite, galena, and sphalerite in silicified andesite porphyry, which could be related to copper porphyry mineralization (McLemore, 1993; unpublished data, NMBMMR).

Richter and others (1986) did not recognize this area as being favorable for the occurrence of porphyry copper deposits, and McLemore (1993) does not believe that there is a high probability of a porphyry deposit occurring within one km of the surface. However, based on the evidence presented and the known exploration history of the area, the assessment team estimated a 10 percent probability of one undiscovered porphyry copper-molybdenum deposit, and a one percent probability of 2 or more of these undiscovered deposits. In addition, the team estimated a one percent probability of one or more undiscovered porphyry molybdenum, low fluorine deposits. Results of the computer simulation are shown in **table 6-3**. Computer simulations show a 70 percent chance of no undiscovered porphyry copper-molybdenum deposits, a 27 percent probability of one deposit, and a 3 percent probability of 2 or more deposits. The mean number of expected undiscovered deposits is 0.3221. Expected means of tonnages are 310 million tonnes of mineralized material containing 1.5 million tonnes Cu, 46,000 tonnes Mo, 510 tonnes Ag, and 5.3 tonnes Au. The simulation for undiscovered porphyry molybdenum, low fluorine deposits determined a 97 percent probability of no such undiscovered deposits, and a 3 percent probability of one or more deposits. The mean number of expected deposits is 0.0286. Expected mean metal tonnage is 4,700 tonnes Mo, contained in 6.5 million tonnes of mineralized material.

Tres Hermanas Favorable Area

Tres Hermanas favorable area includes the Tres Hermanas mining district, where a few small carbonate-hosted mineral deposits are located. The area lies within a gravity high covering part of southern Luna County that corresponds with seismic data (Klein and Abrams, this volume), suggesting that bedrock is within about 900 ft of the surface. Magnetic data is not available for this area. Geochemical anomalies of As, Ba, Be, Bi, spot Cd, Co, Cr, K, La, Mn, Mo, Pb, Sb, Th, Ti, Y, and Zn have been identified in stream-sediment samples (Hassemer, unpublished data, 1995). The boundary is based mainly on gravity and seismic data.

This area has the highest probability for numbers of undiscovered porphyry copper-molybdenum deposits. The estimate shows a 10 percent probability of one deposits, a 5 percent probability of 4 such deposits, and a one percent probability of 5 such deposits. Results of the computer simulation are shown in **table 6-3**. Computer results show a 70 percent probability of no undiscovered porphyry copper-molybdenum deposits, a 20.8 percent probability of one such deposit, 1.7 percent probabilities of 2 or 3 deposits, a 2.8 percent probability of 4 deposits, and a 3 percent probability of 5 or more deposits. The mean number of deposits expected is 0.5567.

Expected mean tonnage of metal contained in these deposits is 2.6 million tonnes Cu, 78,000 tonnes Mo, 840 tonnes Ag, and 9.1 tonnes Au contained in 540 million tonnes of mineralized material.

Tyrone-White Signal Favorable Area

Tyrone-White Signal favorable area includes the Tyrone and White Signal mining districts, which are known to contain large porphyry copper deposits and their inferred extensions. Known porphyry copper deposits have geological, geochemical, and geophysical signatures that may be applied to other areas to help determine their favorability. Geochemical data from the nonmagnetic fraction of stream-sediment samples are anomalous in Ag, Be, Bi, Cu, F, Mo, Nb, Pb, V, and W (Richter and others, 1986). White Signal porphyry deposit is an aeroradiometric Th high.

Richter and others (1986) include this area with those areas considered favorable for the occurrence of porphyry copper and stockwork molybdenum deposits. Criteria used include the presence of known porphyry copper deposits, the existence of base- and precious-metal vein and replacement deposits, presence of the Lower Tertiary quartz monzonite porphyry and quartz monzonite Tyrone stock, pronounced NE- to ENE-trending fault-fracture zones, and potassic and phyllic alteration. Other criteria recognized by Richter and others (1986) include the presence of copper and turquoise veins, areas of pyritization, geochemical anomalies of Ag, Bi, Cu, Mo, Pb, W, and possible Au, Be, F, Nb, and V in nonmagnetic panned stream-sediment samples. Locally, anomalous Ag, Ba, Be, Cu, Pb, S, and Zn may be present in both the magnetic and nonmagnetic fractions of stream-sediment samples.

Based on the above information and a site visit to the Tyrone mine, the assessment team estimated a 10 percent probability of 2 undiscovered porphyry copper-molybdenum deposits, a 5 percent probability of 3 such deposits, and a one percent probability or 4 or more such deposits. There is a 60 percent probability of no undiscovered deposits of this type, a 20 percent probability of one such deposit, a 12 percent probability of 2 deposits, a 4.5 percent probability of 3 deposits, and a 3 percent probability of 4 or more deposits. The mean number of deposits expected is 0.6969 (**table 6-3**). Expected mean tonnages of metals are 3.7 million tonnes Cu, 99,000 tonnes Mo, 1,100 tonnes Ag, and 13 tonnes Au, contained in 710 million tonnes of mineralized material.

Victorio Favorable Area

Victorio favorable area boundary is based upon a gravity high that extends beneath the area, and in corresponding gravity measurements and seismic data sets that indicate that bedrock lies less than one km from the surface. The area includes the Victorio mining district, which has had substantial past mineral production. The southwestern boundary is based upon an aeroradiometric K low, probably indicating the extent of carbonate rocks. A distinctive aeroradiometric K, U, and

Th anomaly indicative of the presence of carbonate rocks is also present. Geochemical anomalies for Be, spot Bi, Co, spot La, Mn, Pb, and Zn in stream-sediment samples indicate the potential for mineral deposits, and drill-hole data indicates Mo-Be deposits at depth.

Available geological, geochemical, and geophysical evidence indicated to the assessment team that there is a one percent probability of one or more undiscovered porphyry copper-molybdenum deposits. Results of the MARK-3 computer simulation (**table 6-3**) show a 97 percent probability of no undiscovered porphyry copper-molybdenum deposits and a 3 percent probability of one or more such deposits. The mean number of deposits expected is 0.0304. Expected mean metal tonnages are 120,000 tonnes Cu, 3,500 tonnes Mo, 44 tonnes Ag, and 0.43 tonnes Au contained in 23 million tonnes of mineralized material.

Undiscovered Resources In Porphyry Deposits

Computer simulations using the estimates provided by the assessment team indicated an expected mean of 7.0589 undiscovered porphyry copper-molybdenum deposits in the 14 favorable areas. About 9.5 (or 68 percent) of the areas could be expected to contain no such deposits, and 4.5 (or 32 percent) of the areas could contain 1-5 such deposits, comprising the total expected mean. Another 0.1000 undiscovered porphyry molybdenum, low fluorine deposits are expected in the two areas where that deposit type is favorable. Estimated undiscovered resources in porphyry copper-molybdenum and porphyry molybdenum, low fluorine deposits at various probabilities are shown in **figure 6-4**. Molybdenum and (B), porphyry molybdenum, low fluorine deposits, Mimbres Resource Area.

At the 90 percent probability (or confidence) level, porphyry copper-molybdenum deposits are expected to contain 26 tonnes Au, 2,600 tonnes Ag, 8.4 million tonnes Cu, and 310,000 tonnes Mo, contained in 2.0 billion tonnes of mineralized material. That is, using the team estimates for porphyry copper-molybdenum deposits in the study area, the computer simulation program determined there is a 90 percent probability (9 chances out of 10) of the stated large volumes of Au, Ag, Cu, and Mo in undiscovered deposits of that type. At the 50 percent confidence level (1 chance out of 2), porphyry copper-molybdenum deposits are expected to contain 86 tonnes Au, 8,200 tonnes Ag, 28 million tonnes Cu, and 810,000 tonnes Mo contained in 6.0 billion tonnes of mineralized material, and at the 10 percent confidence level (1 chance out of 10), these deposits are expected to contain 270 tonnes Au, 23,000 tonnes Ag, 75 million tonnes Cu, and 1.9 million tonnes Mo in 14 billion tonnes of mineralized material.

In the case of porphyry molybdenum, low fluorine deposits, there is a greater than 90 percent probability of no undiscovered resources. At the 5 percent confidence level, 61,000 tonnes of Mo may occur in 74 million tonnes of mineralized material. Stated another way, computer

simulation based on the team assessments determined there is a one in 20 chance of 61,000 tonnes Mo in undiscovered porphyry molybdenum, low fluorine deposits in the study area.

Expected mean tonnages in areas favorable for porphyry copper-molybdenum deposits are estimated to be 36 million tonnes Cu, 980,000 tonnes Mo, 11,000 tonnes Ag, and 120 tonnes Au, contained in 7.1 billion tonnes of mineralized material. Another expected mean of 16,000 tonnes Mo are contained in 21 million tonnes of mineralized material in undiscovered porphyry molybdenum, low fluorine deposits in the Lordsburg and Steeple Rock favorable areas.

CARBONATE-HOSTED DEPOSITS

Carbonate-hosted deposit types occurring in and permissive in the study area include copper, iron, tungsten, zinc-lead, and gold-bearing skarn deposits, polymetallic replacement deposits, Rio Grande Rift lead-zinc deposits, and replacement manganese deposits. The permissive tract for the occurrence of these deposits covers most of the study area, with the nonpermissive tracts identified (**plate 3**).

Delineation of the permissive tract is based on several factors. The tract includes areas where carbonate rocks are thought to be present within one km of the present-day surface, and where carbonate rock may have been replaced by economic elements such as metals carried in hydrothermal fluids. In the study area, the permissive tract includes areas where Mesozoic and Tertiary alkaline or calc-alkaline intrusive rocks are in contact with Paleozoic carbonate units, since replacement deposits and skarn deposits form at or near these contacts. The tract includes areas where gravity and magnetic anomalies indicate the presence of buried intrusions that may have provided a source of heat, pressure, and hydrothermal fluids to produce skarn or replacement deposits. Seismic refraction lines in parts of the study area show subsurface uplift and the presence of possible carbonate host rocks within one km of the surface. The permissive tract includes mining districts where carbonate-hosted deposits have been reported.

Tracts nonpermissive for carbonate-hosted deposits occur where Precambrian igneous rocks crop out, where extensive tracts of Tertiary intrusive rocks are exposed, or where carbonate rocks are buried in deep basins having greater than one km of valley fill. Gravity lows may be indicative of such basins. Where Precambrian igneous rocks are exposed and where extensive exposures of Tertiary intrusive rocks are present, there are no Paleozoic or younger carbonate rocks to act as hosts for mineralization. North of the Piños Altos-Santa Rita favorable area, for example, a nonpermissive tract is defined by a gravity low, Precambrian rocks in outcrop, and by the presence of deep sedimentary basins.

Additionally, carbonate rocks exposed some distance from Mesozoic or Tertiary igneous rocks are not permissive for the occurrence of skarn deposits, since no igneous heat source is

present to produce skarn-type calc-silicate mineralization. Lack of distinctive aeroradiometric K, U, and Th anomalies indicative of the presence of mineralized carbonate rock or an indistinct aeroradiometric signature in exposed rocks are characteristic of nonpermissive tracts.

In the Silver City quadrangle, several areas north of Silver City were outlined by Richter and others (1986) as favorable for the occurrence of copper, iron, zinc-lead, and gold-bearing skarn deposits, owing to the presence of porphyry copper deposits and other precious metal-bearing deposit types. In the Douglas quadrangle, several areas outlined by Hammarstrom and others (1987) as favorable for the occurrence of other types of skarn and associated deposits are favorable also for the occurrence of gold-bearing skarn deposits. They include the Rincon and Gillespie districts, an area south of Granite Gap, and a large area stretching from north of the Eureka district southward to the Mexico border, including Apache No. 2 and Fremont districts to the east. Although gold-bearing skarn deposits were not specifically addressed in the assessment of the Van Horn-El Paso quadrangles (Johnson and others, 1987), the area surrounding the Tres Hermanas mining district was outlined as favorable for the occurrence of copper, iron, and zinc-lead skarn deposits and associated deposit types, and can be interpreted as also favorable for gold-bearing skarn deposits.

In this study, favorable areas are delineated by the presence of base- and precious-metal anomalies, which may be indicative of mineralization. The occurrence of manganese oxides in veins or disseminations in carbonate rocks may help identify replacement manganese mineralization. Structurally favorable areas have faulted carbonate rocks. Areas where carbonate rocks are capped by shale beds acting as impermeable traps for mineralizing fluids promote increased replacement mineralization in the carbonate beds. Gravity and magnetic anomalies are used to identify buried plutons that may have supplied heat, hydrothermal solutions, and metals to form mineral deposits, and aeroradiometric anomalies may suggest enrichment or depletion of radiogenic elements as a result of hydrothermal activity.

Within several of the outlined areas designated as favorable for the occurrence of carbonate-hosted deposits, areas favorable for the occurrence of skarn deposits are indicated. That is, within the favorable carbonate-hosted terranes, there are sub-areas that are in close proximity to an intrusion or source of heat where calc-silicate alteration may have taken place, forming skarn deposits. These areas were selected on the basis of their proximity to igneous rocks, their geophysical indicators for buried igneous rocks, and on the presence of known skarn deposits. Favorable areas are described below.

Using available geological, geophysical, and geochemical information, and information on the mineral occurrences in the study area and adjacent to it, the assessment team estimated the

numbers of undiscovered copper, iron, tungsten, zinc-lead, and gold-bearing skarn deposits, polymetallic replacement, Rio Grande Rift lead-zinc, and replacement manganese deposits at the 90, 50, 10, 5, 1, 0.5, and 0.1 percent confidence levels (probabilities). Results of the computer simulations are shown in **table 6-4**, **table 6-5**, and **table 6-6**.

Areas Favorable for the Occurrence of Carbonate-Hosted Deposits

Big Hatchets Favorable Area

In delineating the Big Hatchets favorable area, it was recognized that the identified mineral deposits occur in an area that is underlain by a gravity high. The high corresponds with shallow high velocity rocks on the southwest and east, as seen in the seismic data (Klein, this volume). The boundary of the area encompasses the gravity high and the area between the outstretched "fingers" of the high. The area includes the minor carbonate-hosted deposits of the Big Hatchet Mountains mining district and locations where Paleozoic carbonate rocks crop out. Drewes and others (1988) selected an area in the Big Hatchet Mountains as having a potential for mineralization--this area is included in the favorable area. Geochemical anomalies of As, Cd, Sn, and Ti occur in the mining district. Co, Mn, U, and scattered Nb are noted on the south end of the range. A distinctive aeroradiometric K, U, and Th anomaly indicating the presence of carbonate rocks covers part of the area.

Estimates for the presence of undiscovered carbonate-hosted polymetallic replacement, replacement manganese, and Rio Grande Rift lead-zinc deposits are shown in **table 6-4**, **table 6-5**, and **table 6-6**.. There is insufficient evidence for estimating the probability of the occurrence of skarn deposits. Results of the computer simulations using team estimates show that the expected mean numbers of undiscovered carbonate-hosted deposits are 0.0278 polymetallic replacement, 0.0278 replacement manganese, and 1.2681 Rio Grande Rift lead-zinc deposits. The total expected mean amounts of metals in these undiscovered carbonate-hosted deposits are 0.83 tonnes Au, 43 tonnes Ag, 530 tonnes Cu, 1,900 tonnes Mn, 14,000 tonnes Pb, and 9,200 tonnes Zn in 270,000 tonnes of mineralized material. The bulk of these metals and 63 percent of the mineralized material occur in undiscovered polymetallic replacement deposits. This deposit type accounts for greater than 99 percent of the Zn, 99 percent of the Ag, 96 percent of the Au, and 84 percent of the Pb in undiscovered carbonate-hosted deposits; undiscovered Rio Grande Rift lead-zinc deposits account for only a small portion of the precious and base metals.

Carpenter Favorable Area

Delineation of the Carpenter favorable area was based on the presence of part of the Carpenter mining district that has known polymetallic vein and replacement deposits, exposures of

carbonate rocks, and the presence of a magnetic high that may be indicative of buried intrusions beneath the known mineralized sites. The district lies in a gravity low. Team estimates of the probability of undiscovered polymetallic replacement, replacement manganese, and Rio Grande Rift lead-zinc deposits are shown in **table 6-4** and **table 6-5**. There was insufficient probability for the occurrence of undiscovered skarn deposits to make estimates.

Computer simulation shows expected means of 0.6159 undiscovered Rio Grande Rift lead-zinc deposits, 0.1056 polymetallic replacement deposits, and 0.4175 replacement manganese deposits. A mean of 820,000 tonnes of mineralized material is expected in undiscovered carbonate-hosted deposits. Expected means of metals in these deposits are 0.54 tonnes Au, 150 tonnes Ag, 1,200 tonnes Cu, 38,000 tonnes Mn, 40,000 tonnes Pb, and 40,000 tonnes Zn. As in the Big Hatchet area, polymetallic replacement deposits comprise most of the undiscovered metals. That deposit type is expected to account for about 100 percent of the Zn, 97.4 percent of the Pb, 99.7 percent of the Ag and Au, and 79 percent of the mineralized material in undiscovered carbonate-hosted deposits.

Cookes Range Favorable Area

Cookes Range favorable area was delineated to include the Northern Cookes Range, Cookes Range, Old Hadley, and Fluorite Ridge mining districts and exposures of carbonate and igneous intrusive rocks. Known mineral deposits include polymetallic replacements and veins and other types of hydrothermal deposits. The outline of the area follows a gravity high underlying the mineralized parts of the area. Magnetic culminations occur beneath northern and southern parts of the area. A magnetic high in the northern Potrillo Mountains forms the southern boundary. Seismically defined uplift occurs in the southern part of the area, as well. The northern part of the area is considered favorable for the occurrence of skarn deposits, based on the proximity of carbonate rocks to Tertiary igneous intrusive rocks.

Team estimates of undiscovered carbonate-hosted mineral deposits are shown in **table 6-4** and **table 6-5**. Results of computer simulation using the estimates (table 6-5) determined that there are expected means of 0.1074 polymetallic replacement, 1.4799 replacement manganese, and 0.6281 Rio Grande Rift lead-zinc deposits. The part of the area that is favorable for the occurrence of skarn deposits contains an expected mean of 0.0302 copper skarn deposits, 0.0268 gold-bearing skarn deposits, 0.0058 zinc-lead skarn deposits, and 0.0676 iron skarn deposits. Total expected mean tonnages of metals in undiscovered deposits are 0.82 tonnes Au, 140 tonnes Ag, 3,600 tonnes Cu, 35,000 tonnes Pb, 39,000 tonnes Zn, 120,000 tonnes Mn, and 2.5 million tonnes Fe contained in 6.8 million tonnes of mineralized material. Skarn deposits account for approximately 37 percent of the Au, 2.3 percent of the Ag, 62 percent of the Cu, 1.4 percent of the

Pb, 3.9 percent of the Zn, none of the Mn, 100 percent of the Fe, and 84 percent of the mineralized material.

Doña Ana Favorable Area

Doña Ana favorable area was delineated by the Doña Ana mining district and its constituent mineral occurrences. The presence of a gravity high marking the northern wall of the Doña Ana caldera was used to extend the area beyond the area of known exposures; known mineralization occurs on the gravity high. A magnetic high occurs on the southern edge of the gravity high and indicates intercaldera intrusion. The eastern half of the area was selected as favorable for the occurrence of skarn deposits, owing to the presence of exposed Paleozoic carbonate rocks in close proximity to Tertiary intrusive rocks.

Team estimates of the undiscovered carbonate-hosted mineral deposits are shown in **table 6-4**. The area was considered favorable for the occurrence of undiscovered replacement manganese deposits (50 percent probability of 2 deposits) and Rio Grande Rift lead-zinc deposits (50 percent probability of one deposit, 10 percent probability of 2 deposits, one percent probability of 3 deposits), and only slightly favorable for the occurrence of polymetallic replacement deposits (1 percent probability of one deposit). Results of the computer simulation show that the mean numbers of undiscovered deposits expected to occur in the favorable area are 0.0296 polymetallic replacement, 1.4597 replacement manganese, and 1.0162 Rio Grande Rift lead-zinc deposits. These deposits have expected means of 0.10 tonnes Au, 55 tonnes Ag, 370 tonnes Cu, 14,000 tonnes Pb, 12,000 tonnes Zn, and 130,000 tonnes Mn contained in 710,000 tonnes of mineralized material. The area favorable for the occurrence of skarn deposits adds an additional 0.0064 copper skarn deposits, 0.0080 gold-bearing skarn deposits, 0.0096 zinc-lead skarn deposits, and 0.0822 iron skarn deposits. Expected means for metals in skarn deposits are 0.10 tonnes Au, 0.78 tonnes Ag, 900 tonnes Cu, 290 tonnes Pb, 850 tonnes Zn, and 3.2 million tonnes Fe contained in 6.4 million tonnes of mineralized material. This amounts to 51 percent of the expected mean tonnage of Au, 71 percent of the Cu, 100 percent of the Fe, and 90 percent of the mineralized material for the favorable area.

Florida Favorable Area

Florida favorable area is delineated by a gravity high covering known mineral occurrences and extending beyond the known mineralized area. A magnetic high occurs in the southwestern part of the favorable area, which lies at the northern boundary of a thrust belt and at the southern margin of the Texas lineament. All of the Florida Mountains mining district and the southern half of the Little Florida Mountains district are included in the favorable area. Known mineralization includes epithermal and hydrothermal deposits that have had moderate production. Within the

Florida Mountains district, geochemical anomalies of Ba, Be, spot Bi and Cd, Co, Cr, Cu, K, La, Mn, Nb, Pb, Sn, Th, Ti at the south end, Y, and Zn occur; the north end of the district has additional As and Sb anomalies. There is an aeroradiometric K relative low in the district. The western part of the area was selected as being favorable for the occurrence of skarn deposits owing to the suspected presence of buried Paleozoic carbonate rocks in close proximity to Tertiary intrusive rocks. A small area non-permissive for carbonate-hosted deposits is outlined further to the west.

The assessment team estimated the probability of undiscovered replacement, Rio Grande Rift lead-zinc, and skarn deposits. The estimates are shown in **table 6-4**. According to those estimates, replacement manganese deposits are the most likely types of deposits to occur (90 percent probability of one deposit), followed by iron skarn deposits (10 percent probability of one deposit), Rio Grande Rift lead-zinc (50 percent probability of one deposit, 10 percent probability of 2 deposits, one percent probability of 3 deposits), copper skarn and polymetallic replacement (1 percent probability of one deposit), and zinc-lead skarn (0.5 percent probability of one deposit). Results of the computer simulation show that the mean numbers of deposits expected are 0.0324 polymetallic replacement, 1.0104 replacement manganese, and 0.9970 Rio Grande Rift lead-zinc deposits. That part of the area favorable for the occurrence of skarn deposits is expected to add another 0.0292 copper, 0.0068 gold-bearing, 0.0096 zinc-lead, and 0.2863 Fe skarn deposits. Together, these deposits are expected to contain means of 0.20 tonnes Au, 33 tonnes Ag, 6,100 tonnes Cu, 13,000 tonnes Pb, 15,000 tonnes Zn, 84,000 tonnes Mn, and 12 million tonnes Fe, contained in 26 million tonnes of mineralized material. Of these metals, skarn deposits contain approximately 93 percent of the copper and 100 percent of the iron. Most of the expected mean gold (67 percent) and 93 percent of the silver are in polymetallic replacement deposits.

Gillespie Favorable Area

Delineation of Gillespie favorable area is by occurrence of known hydrothermal mineralization, exposures of carbonate rocks, and the location of a gravity high indicating a wall separating two calderas beneath known sites of mineralization. A magnetic high, which has been identified by drilling to be a quartz monzonite intrusion, is located in the center of the area, and is centered on the gravity anomaly. Estimates were made for the probability of polymetallic replacement, replacement manganese, and Rio Grande Rift lead-zinc deposits (50 percent probability of one deposit). Replacement manganese and Rio Grande Rift deposits are the most likely undiscovered deposits to occur. Polymetallic replacement lead-zinc deposit are less likely (1 percent probability of one deposit). There was insufficient probability for the occurrence of skarn deposits to make an estimate. Computer simulation results show an expected mean of 0.7163

undiscovered replacement manganese deposit, 0.0310 undiscovered polymetallic replacement deposit, and 0.9996 Rio Grande Rift lead-zinc deposits. These deposits are expected to contain mean metal tonnages of 0.17 tonnes Au, 43 tonnes Ag, 380 tonnes Cu, 68,000 tonnes Mn, 15,000 tonnes Pb, and 13,000 tonnes Zn in 510 million tonnes of mineralized material. Polymetallic replacement deposits account for 99 percent of the Au, almost 100 percent of the Ag and Zn, 89 percent of the Pb, and 44 percent of the mineralized material in undiscovered carbonate-hosted deposits.

Little Hatchet-Sierra Rica Favorable Area

Little Hatchet-Sierra Rica favorable area is delineated by the extension of a gravity high underlying areas of known mineralization. The presence of known mineral deposits and exposures of Paleozoic carbonate and Tertiary intrusive rocks were important factors in determining the boundary. The area includes contiguous areas of the Apache No. 2, Eureka, Fremont, and Sylvanite mining districts, and an area extending from the Eureka district in a northward arc to Black Mountain and the eastern side of the Cedar Mountains.

Four mining districts have had moderate production and have potential for additional undiscovered deposits. Apache No. 2 district has known carbonate-hosted mineralization. The district sits on regional gravity and magnetic highs and is on a northwest-trending structure paralleling the Texas lineament. Magnetic highs beneath likely carbonate rocks indicate intrusive rocks and probable areas for skarn development. Distinctive aeroradiometric K, U, and Th anomalies indicative of the presence of carbonate rocks occur here and in the adjacent Fremont district. Geochemical anomalies of As, Bi, Cd, Co, Cu, K, La, Mo, Sb, Th, U, Y, and Zn occur in stream-sediment samples.

Fremont district lies on the edge of the Apache Hills caldera and has identified epithermal mineralization. A buried porphyry system may be present in the district, as well as other types of undiscovered mineral deposits. The district lies on the same regional gravity and magnetic highs and northwest-trending structure as the Apache No. 2 district. Geochemical stream-sediment anomalies include As, Cd, and Sb, and spot anomalies of Bi and Pb.

Eureka and Sylvanite districts are proximal and have geological similarities. Both districts are the sites of known skarn deposits. They are located on a gravity high, and partial distinct magnetic highs occur beneath the west side of each district. A variety of geochemical stream-sediment anomalies occur; distinctive aeroradiometric K, U, and Th anomalies signify the presence of carbonate rocks.

Four parts of the Little Hatchet-Sierra Rica favorable area (Carrizalillo, Eureka-Sylvanite, North Hatchet, and Sierra Rica areas) are favorable for the occurrence of undiscovered skarn

mineralization based on the presence of exposed Paleozoic carbonate rocks and those in the subsurface, Tertiary intrusive rocks, magnetic highs beneath likely carbonate rocks, and known skarn deposits. Carrizalillo area was delineated on the basis of a magnetic high and exposures of suitable host rocks. The magnetic high borders a gravity high that underlies the northern Carrizalillo and North Hatchet areas and the Little Hatchet Mountains.

North Hatchet area was delineated on the basis of a magnetic high that borders a larger gravity high. Seismic refraction identified high-velocity rocks at approximately 800 m depth where magnetic and gravity data form a combined anomaly in northern Playas Valley.

Estimates shown in **table 6-4** indicate that Rio Grande Rift lead-zinc deposits are the most likely (90 percent probability of one deposits, 50 percent probability of 2 deposits, and one percent probability of 3 deposits). Polymetallic replacement, replacement manganese, copper skarn, and zinc-lead skarn deposits have a 50 percent probability of one deposit. Tungsten skarn and gold-bearing skarn deposits have a 10 percent probability of one deposit, and iron skarn deposits have a 5 percent probability of 2 deposits. Using the team estimates, the computer determined that the mean number of deposits expected is 1.2663 Rio Grande Rift lead-zinc deposits, 0.7578 polymetallic replacement deposits, and 0.7570 replacement manganese deposits. Areas favorable for the occurrence of skarn deposits are expected to contain an additional 0.9378 copper skarn deposits, 0.4077 gold-bearing skarn deposits, 1.0812 zinc-lead skarn deposits, 0.3230 iron skarn deposits, and 0.3269 tungsten skarn deposits. Expected means of tonnages of metal in these deposits are 12 tonnes Au, 1,200 tonnes Ag, 100,000 tonnes Cu, 390,000 tonnes Pb, 570,000 tonnes Zn, 69,000 tonnes Mn, 12,000 WO_3, and 13 million tonnes Fe contained in 110 million tonnes of mineralized material. Skarn deposits are expected to contain approximately 66 percent of the gold, 89 percent of the copper, and all of the tungsten and iron. Skarn deposits, however, will contain only approximately 37 percent of the Pb and 52 percent of the Zn in carbonate-hosted deposits. Most of the remaining lead (63 percent) and zinc (48 percent) are expected to occur in polymetallic replacement deposits. Approximately 0.54 percent of the lead is expected to occur in undiscovered Rio Grande Rift lead-zinc deposits.

Lordsburg-Animas Favorable Area

Lordsburg-Animas favorable area stretches southward from Lordsburg Mesa and includes Lordsburg, Muir, and Rincon districts. The outline of the area is based on the presence of these districts, exposures of Paleozoic carbonate rocks, occurrences of known mineralization in the districts, and extensions of the districts to include the limits of a gravity high that underlies the known mineralization. Magnetic highs in the Pyramid Mountains, Muir caldera, and areas bordering the southern Animas Mountains indicate intrusions into carbonate rocks. Seismic and

gravity information shows that carbonate rocks are within 400 m of the surface in the valley between the Animas and Little Hatchet Mountains. Lordsburg Mesa is included, owing to the presence of a large area of limonitic alteration and a gravity high.

Lordsburg district is the site of known polymetallic vein deposits and, where mineralizing solutions contacted carbonate rocks, possible undiscovered carbonate-hosted deposits. Both magnetic and gravity highs are recognized in the district. Andesites in the district are silicified and oxidized. Reported geochemical stream-sediment anomalies include Ag, Be on the north end of the district, spot Ba, Co, Cr, Cu, K to the east, La, Mn, Mo, Nb on the north end of the district, Pb, spot Sn, Th on the north and south ends of the district, Ti, and Y to the northwest. Aeroradiometric K, U, and Th are undistinguished.

Muir district lies along Muir caldera (on the flank of a gravity high) and on the edge of a magnetic high probably caused by a felsic intrusion into the caldera. Paleozoic carbonate rocks may be buried. The associated gravity high and uplift are seen in the seismic refraction data (Klein, this volume). The magnetic high may indicate the presence of the intrusion, skarn deposits, or both. Reported geochemical stream-sediment anomalies include Ag, Ba, Be, spot Cd, Co, Cr on the west side of the district, K to the west, Mo, Pb, U on the northwest, Y, and Zn, and scattered anomalies of Mn, Nb, Sn, Th, and Ti. Rincon district is the site of identified carbonate-hosted and epithermal vein occurrences. A gravity high and magnetic low are present in the district. Geochemical stream-sediment samples yielded anomalies of As, Cd, Cu, La, spot Pb, and Nb on the southern end of the district.

Animas, Lordsburg, and Muir areas are favorable for the occurrence of skarn deposits, based on the presence of carbonate rocks in close proximity to exposed Tertiary intrusive rocks. Animas area includes part of the Rincon district; the Lordsburg and Muir areas include parts of the mining districts with the same names.

Estimates of the numbers of undiscovered carbonate-hosted deposits in the Lordsburg-Animas favorable area are shown in **table 6-4**. In the area, replacement manganese deposits have the highest probability of occurring (90 percent probability of one deposit) followed by iron skarn deposits and Rio Grande Rift lead-zinc deposits (50 percent probability of one deposit), copper skarn deposits (10 percent probability of one deposit), polymetallic replacement deposits (5 percent probability of one deposit), and gold-bearing and zinc-lead skarn deposits (1 percent probability of 2 deposits). Results of the computer simulation indicate that the expected mean numbers of deposits are 1.2965 replacement manganese deposits, 1.0332 Rio Grande Rift lead-zinc deposits, and 0.0724 polymetallic replacement deposits. In addition, the three areas favorable for skarn deposits are expected to contain means of 0.3195 copper skarn deposits,

0.0964 gold-bearing skarn deposits, 0.0704 zinc-lead skarn deposits, and 0.7079 iron skarn deposits. The total of these deposits gives expected means of 1.4 tonnes Au, 140 tonnes Ag, 22,000 tonnes Cu, 37,000 tonnes Pb, 50,000 tonnes Zn, 110,000 tonnes Mn, and 31 million tonnes Fe contained in 62 million tonnes of mineralized material. Of these amounts, approximately 1.1 tonnes Au, 23 tonnes Ag, 21,000 tonnes Cu, 7,900 tonnes Pb, 20,000 tonnes Zn, and 31 million tonnes Fe, are contained in skarn deposits. Of the areas favorable for the occurrence of skarn deposits, the Lordsburg area has, by far, the greatest potential for undiscovered deposits. In this area alone, the expected number of deposits is 0.2907 copper skarn deposits, 0.0578 gold-bearing skarn deposits, 0.0594 zinc-lead skarn deposits, and 0.6913 iron skarn deposits containing 0.78 tonnes Au, 19 tonnes Ag, 18,000 tonnes Cu, 6,600 tonnes Pb, 16,000 tonnes Zn, and 30 million tonnes Fe, in 60 million tonnes of mineralized material.

Peloncillo Favorable Area

Peloncillo favorable area includes McGhee Peak and Granite Gap mining districts, and an area to the south where scattered manganese mineralization occurs. The mining districts contain carbonate-hosted replacement and skarn deposits that have had moderate past production. Granite Gap and McGhee Peak districts are located on an elongate gravity high with an associated magnetic high. Identified geochemical anomalies of Be, Mo, Nb, Pb, Th, and U, and spot anomalies of Be, Cr, and Sn occur in stream-sediment samples. Present in Granite Gap district area is an area of known carbonate rocks and Tertiary granite and an area of high resistivity having edges that follow the magnetic high. An aeroradiometric low occurs at the north end of the district; K, U, and Th are higher to the south. The northern part of McGhee Peak district is underlain by a Cretaceous and Early Tertiary andesite sequence that is propylitically altered, and hosts epithermal deposits. This part of the area is favorable for the occurrence of skarn deposits, owing to the close proximity of carbonate rocks, Tertiary granite, and other intrusive rocks.

Team estimates of the probabilities of undiscovered carbonate-hosted deposits are shown in **table 6-4**. Copper skarn and Rio Grande Rift lead-zinc were determined to be the most likely deposit types to occur (50 percent probability of one deposit). Polymetallic replacement (10 percent probability of 2 deposits), replacement manganese, and tungsten skarn deposits (10 percent probability of one deposit) are the next most likely. Gold-bearing, iron, and zinc-lead skarn deposits were determined to be the least likely of the carbonate-hosted deposits to occur in the favorable area (0.1 percent probability of one deposit). Results of the computer simulation show that the expected numbers of deposits are 1.0324 Rio Grande Rift lead-zinc deposits, 0.6507 replacement manganese deposits, and 0.2897 polymetallic replacement deposits. That part of the area favorable for skarn deposits is expected to contain means of 0.7199 copper skarn deposits,

0.0024 gold-bearing skarn deposits, 0.0030 zinc-lead deposits and iron skarn deposits, respectively, and 0.2903 tungsten skarn deposits. Carbonate-hosted deposits are expected to contain means of 2.2 tonnes Au, 360 tonnes Ag, 55,000 tonnes Cu, 100,000 tonnes Pb, 110,000 tonnes Zn, 65,000 tonnes Mn, 9,500 tonnes WO_3, and 49,000 tonnes Fe in 7.3 million tonnes of mineralized material. Of those amounts, 0.63 tonnes Au, 7.1 tonnes Ag, 52,000 tonnes Cu, 340 tonnes Pb, 610 tonnes Zn, 9,500 tonnes WO_3, and 49,000 tonnes Fe occur in skarn deposits. The metals are contained in 5.2 million tonnes of mineralized material in skarn deposits.

Piños Altos-Santa Rita Favorable Area

Piños Altos-Santa Rita favorable area extends from north of San Vincente and Tyrone southward to Mimbres and to the crest of the Piños Altos Mountain Range. The area contains Chloride Flat, Fierro-Hanover, Fleming, Georgetown, Lone Mountain, Piños Altos, and Santa Rita mining districts, sites of porphyry, hydrothermal, and epithermal mineralization, and some of the most productive mining districts in the study area. Many deposits in the districts are carbonate-hosted replacement or skarn deposits.

The area boundary includes known mineral deposits, mining districts, and exposures of Paleozoic carbonate and intrusive rocks. It emulates a gravity high that surrounds known mineral deposits. Some of the large magnetic highs are known to be associated with magnetite in iron skarn deposits. A large magnetic low on the north may be one or all of the following: a dipole-effect of source; reversed magnetization in volcanic rocks; and (or) non-magnetic (altered) volcanic ash of the Twin Sisters caldera. Unlike other favorable areas, this entire area is favorable for both skarn deposits and replacement carbonate-hosted deposits.

Estimates of the numbers of undiscovered carbonate-hosted deposits in the Piños Altos-Santa Rita favorable area are shown in **table 6-4**. Estimates show that copper, iron, and zinc-lead skarn deposits and replacement manganese deposits have a 90 percent probability of occurrence; Rio Grande Rift lead-zinc deposits have a 50 percent probability of occurrence; tungsten skarn has a 10 percent probability of occurrence; and gold-bearing skarn deposits have a 5 percent probability of occurrence. Results of the computer simulation show that the expected mean numbers of deposits are 0.3605 polymetallic replacement, 2.6133 replacement manganese, 1.0304 Rio Grande Rift lead-zinc deposits, and 1.3003 copper skarn deposits, 0.1072 gold-bearing skarn deposits, 1.3069 zinc-lead skarn deposits, 2.2090 iron skarn deposits, and 0.2889 tungsten skarn deposits. These deposits are expected to contain 8.5 tonnes Au, 740 tonnes Ag, 110,000 tonnes Cu, 290,000 tonnes Pb, 460,000 tonnes Zn, 220,000 tonnes Mn, 8,900 tonnes WO_3, and 91 million tonnes Fe in 200 million tonnes of mineralized material. About 51 percent of the expected gold is contained in zinc-lead skarn deposits, and an additional 26 percent is in polymetallic

replacement deposits. Over 56 percent of the silver, 42 percent of the lead, and 28 percent of the zinc is in polymetallic replacement deposits, and 58 percent of the lead and 71 percent of the zinc are in zinc-lead skarn deposits. Approximately 68 percent of the copper is in copper skarn deposits. All Mn is in replacement manganese deposits, and nearly all of the Fe and all of the WO_3 are in skarn deposits. In total, about 94 percent of the mineralized material is in iron skarn deposits.

Potrillo Favorable Area

Potrillo favorable area reaches northward from the New Mexico-Mexico border to west of the Good Sight Mountains, nearly to the village of Florida. The area includes Camel Mountain-Eagle Nest and East Potrillo mining districts, which are the sites of carbonate-hosted and skarn mineral deposits. Tertiary intrusive rocks and Paleozoic carbonate rocks crop out in the East Potrillo district. Seismic refraction shows that elevated bedrock may be Paleozoic carbonate within 300 to 400 m of the surface near Camel Mountain-Eagle Nest district. Geochemical anomalies for that district are spotty.

East Potrillo district has geochemical and geophysical anomalies that suggest favorability for carbonate-hosted mineral deposits. Geochemical stream-sediment samples show that the district is anomalous in As, La, and Zn, and has spot anomalies of Ba and Co; Mn is spotty on the north and south ends of the district, and Ti is anomalous on the south end. Distinctive aeroradiometric K, U, and Th anomalies are indicative of the presence of mineralized carbonate rock. Seismic data indicates that a high-velocity unit representing a pluton beneath the Potrillo Mountains at a depth of 700 m. A broad gravity high underlies the area of known mineralization and extends north-northwest to the Good Sight Range; the favorable area is delineated by the gravity high. A large magnetic high south of the Good Sight Range corresponds to a gravity peak and seismicly defined uplift; a smaller magnetic high is seen northeast of the West Potrillo Mountains. There is no magnetic data south of the northern West Potrillo Mountains. Within the favorable area, Camel Mountain-Eagle Nest, East Potrillo, and Northern Potrillo areas are identified as favorable for the occurrence of skarn deposits, based on the presence of Paleozoic carbonates and Tertiary intrusive rocks.

Team estimates (**table 6-4**, **table 6-5**) indicate that the likelihood for undiscovered carbonate-hosted mineral deposits is low. Rio Grande Rift lead-zinc deposits are the deposit type most likely to occur, having a 50 percent probability of one or more deposits. Replacement manganese and iron skarn deposits are next likeliest deposit types, having a 5 percent probability of occurrence of one deposit. Polymetallic replacement, and copper, gold-bearing, and zinc lead skarn deposits have a one percent probability of occurrence. Computer simulation using team

estimates show expected means of 1.0252 Rio Grande Rift lead-zinc deposits, 0.0570 polymetallic replacement deposits, and 0.0944 replacement manganese deposits in the Potrillo favorable area. Expected means of 0.023 tonnes Au, 72 tonnes Ag, 1,300 tonnes Cu, 21,000 tonnes Pb, 21,000 tonnes Zn and 8,600 tonnes Mn, contained in approximately 470,000 tonnes of mineralized material. Most of the silver, lead, and zinc, and 78 percent of the mineralized material are in polymetallic replacement deposits; manganese is in replacement manganese deposits. Three skarn areas contain 0.0604 undiscovered copper skarn deposits, 0.0370 gold-bearing skarn deposits, 0.0578 zinc-lead skarn deposits, and 0.1104 iron skarn deposits. Expected means are of 0.42 tonnes Au, 17 tonnes Ag, 4,600 tonnes Cu, 7,200 tonnes Pb, 14,000 tonnes Zn, and 4.4 million tonnes of Fe contained in 9.6 million tonnes of mineralized material. About 94 percent of the Au, 100 percent of the Fe, 78 percent of the Cu, 19 percent of the Ag, 26 percent of the Pb, and 41 percent of the Zn in carbonate-hosted deposits occur in skarn deposits.

San Andres-Organ-Franklin Favorable Area

San Andres-Organ-Franklin favorable area extends the full length of the study area, from the northern boundary with Sierra County to the New Mexico-Texas border. It includes Bear Canyon, Black Mountain, Northern Franklin Mountains, Organ, San Andrecito-Hembrillo, and San Andres mining districts. The area was delineated by known mineral deposits and the occurrence of gravity highs. Identified carbonate-hosted vein, replacement, and skarn deposit types and other deposit types are present in these districts. Bear Canyon and Northern Franklin Mountains mining districts and the Bishop Cap area are underlain by gravity highs; Black Mountain, San Andres, and San Andrecito-Hembrillo districts occur on gravity gradients. In the vicinity of Organ, a gravity low breaks up the broad gravity high beneath this area. For the most part, the border of the area represents the surface expression of the gravity high. There is no magnetic data north of Bishop Cap, but the Bishop Cap area and Northern Franklin mining district are on a magnetic high, indicating the presence of an intrusion, mafic basement, or massive, skarned carbonate rock at shallow depth.

The area is favorable for the occurrence of polymetallic replacement deposits, replacement manganese deposits, and Rio Grande Rift lead-zinc deposits. The south-central part of the favorable area, however, from north of St. Augustine Pass to south of Bishop Cap, is favorable for the occurrence of these types of deposits and for the occurrence of skarn deposits, owing to close proximity of Paleozoic carbonate rocks and Tertiary intrusive rocks.

Estimates of the undiscovered carbonate-hosted deposits show that polymetallic replacement deposits have a 90 percent probability of one deposit, copper skarn deposits have a 90 percent probability of one deposit, Rio Grande Rift lead-zinc deposits have a 50 percent probability

of one deposit, replacement manganese and gold-bearing skarn deposits, iron skarn deposits and tungsten skarn deposits have a 10 percent probability of one deposit each, and zinc-lead skarn deposits have a 0.5 percent probability of one deposit. Computer simulation using the estimates determined that the mean numbers of undiscovered carbonate-hosted deposits expected are 1.2242 polymetallic replacement deposits, 1.0246 Rio Grande Rift lead-zinc deposits, and 0.3323 replacement manganese deposits. These deposits have expected means of 6.1 tonnes Au, 1,500 tonnes Ag, 18,000 tonnes Cu, 430,000 tonnes Pb, 460,000 tonnes Zn, and 28,000 tonnes Mn contained in 7.9 million tonnes of mineralized material. Polymetallic replacement deposits contain most of the expected precious and base metals. Expected mean numbers of skarn deposits are 0.7668 copper skarn deposits, 0.3969 gold-bearing skarn deposits, 0.0714 zinc-lead skarn deposits, 0.3689 iron skarn deposits, and 0.3077 tungsten skarn deposits having expected means of 3.5 tonnes Au, 40 tonnes Ag, 64,000 tonnes Cu, 8,100 tonnes Pb, 26,000 tonnes Zn, 9,900 tonnes WO_3, and 17 million tonnes Fe contained in 40 million tonnes of mineralized material. Gold-bearing skarn deposits account for over 90 percent of this gold, but zinc-lead skarn deposits contain approximately half of the silver, all of the lead, and approximately 60 percent of the zinc in skarn deposits. Skarn deposits contain all of the expected mean tonnages of iron and tungsten in carbonate-hosted deposits.

Tortugas Favorable Area

Tortugas area is favorable for the occurrence of undiscovered carbonate-hosted mineral deposits, owing to the known occurrences of polymetallic replacements and replacement manganese occurrences within the area. Carbonate rocks crop out, and the area contains above-normal geothermal potential. Geochemical anomalies include Be, spot Co, La, spot Mo, Mn, Nb, Pb, Th, and U. Aeroradiometric readings are undistinguished. The area lies northwest of a magnetic high. Its boundary was delineated on the basis of a gravity high or ridge connecting the western Organ Mountains and the Doña Ana caldera, and its location below mineralized areas. The gravity high lies on a magnetic gradient connecting the Doña Ana and San Andres-Organ-Franklin favorable areas.

Estimates were made for the probability of polymetallic replacement, replacement manganese, and Rio Grande Rift lead-zinc deposits (**table 6-4**, **table 6-5**). Rio Grande Rift lead-zinc deposits have a 50 percent probability of occurrence of one deposit. There was insufficient probability for the occurrence of skarn deposits to make an estimate. From the computer simulation, expected mean quantities of metals in undiscovered carbonate-hosted deposits are 0.077 tonnes Au, 59 tonnes Ag, 210 tonnes Cu, 30,000 tonnes Mn, 17,000 tonnes Pb, and 11,000 tonnes Zn, in 340,000 tonnes of material. Polymetallic replacement deposits

account for almost all of the expected precious and base metals and 48 percent of the mineralized rock. Replacement manganese deposits account for all of the manganese, and 31 percent of the mineralized rock. Rio Grande Rift lead-zinc deposits account for 21 percent of the mineralized rock in undiscovered carbonate-hosted deposits.

Victorio-Tres Hermanas Favorable Area

Victorio-Tres Hermanas favorable area extends northwestward from the New Mexico-Mexico border, through Tres Hermanas and Victorio districts, to west of the Burro Mountains just south of the Gold Hill district; the mining districts are included. The favorable area was delineated by the presence of the mining districts having carbonate-hosted deposits (including skarn deposits), carbonate and Tertiary intrusive rock, a magnetic anomaly on the southwestern edge of the Burro Uplift where geology indicates possible steeply dipping carbonate, and recognition of a gravity high underlying the area. Part of the same uplift that occurs east of the Victorio Mountains comes to within approximately 300 m of the surface, based on seismic refraction data.

Three parts of the area (Southern Burro Mountains, Tres Hermanas, and Victorio areas) were selected as favorable for the occurrence of copper skarn deposits, gold-bearing skarn deposits, iron skarn deposits, tungsten skarn deposits, and zinc-lead skarn deposits. In each of these areas, carbonate rocks may have contacted intrusive rocks. Tungsten has been produced in Victorio district. Skarn deposits, including tungsten skarn deposits, are recognized in the Tres Hermanas area, and carbonate and Tertiary intrusive rocks crop out. Carbonate rock is exposed in the Victorio district; a magnetic high in the Victorio Mountains provides additional evidence for skarn mineralization. Southern Burro Mountains area was delineated by gravity and magnetic anomalies indicating possible steeply dipping carbonates along the southern edge of exposed Precambrian rock.

Team estimates (**table 6-4**, **table 6-5**) indicate a 90 percent probability of one copper skarn deposit, and 50 percent probabilities of one deposit each of polymetallic replacement skarn deposits, Rio Grande Rift lead-zinc deposits, tungsten skarn deposits, and zinc-lead skarn deposits. Replacement manganese deposits, gold-bearing skarn deposits, and iron skarn deposits skarn deposits have 10 percent probabilities of one deposit each in the favorable area.

Computer simulation determined that the expected mean numbers of undiscovered deposits are 0.6993 polymetallic replacement deposits, 0.3577 replacement manganese deposits, and 0.9958 Rio Grande Rift lead-zinc deposits. These deposits would contain an expected mean of 2.9 tonnes Au, 930 tonnes Ag, 12,000 tonnes Cu, 30,000 tonnes Mn, 250,000 tonnes Pb, and 240,000 tonnes Zn contained in 4.5 million tonnes of mineralized material. The relatively large

expected mean number of undiscovered polymetallic replacement deposits results in almost all of the base and precious metals originating in deposits of that type.

Computer simulations based on the team estimates show the significant potential these areas have for undiscovered skarn deposits, translating into large amounts of undiscovered metals. In Southern Burro Mountains area, expected means for numbers of deposits are 0.0082 undiscovered copper skarn deposits, 0.0082, gold-bearing skarn deposits, 0.0032, zinc-lead skarn deposits, 0.0038 iron skarn deposits, and 0.0282 tungsten skarn deposits. These deposits have expected means of 0.63 tonnes Au, 1.4 tonnes Ag, 710 tonnes Cu, 580 tonnes Pb, 1,800 tonnes Zn, 1,100 tonnes $WO_{3,}$ and 300,000 tonnes Fe contained in 740,000 tonnes of mineralized material. Tres Hermanas area is expected to have a mean of 1.2426 copper skarn deposits, 0.0746 zinc-lead skarn deposits, 0.0288 tungsten skarn deposits, and 0.3707 iron skarn deposits. These deposits are expected to have means of 3.7 tonnes Au, 39 tonnes Ag, 79,000 tonnes Cu, 9000 tonnes Pb, 25,000 tonnes Zn, 660 tonnes WO_3, and 16 million tonnes Fe contained in 41 million tonnes of mineralized material. Victorio area contains expected means of 0.7165 undiscovered copper skarn deposits, 0.3687 gold-bearing skarn deposits, 0.7742 zinc-lead skarn deposits, 0.3799 iron skarn deposits, and 0.8208 tungsten skarn deposits, which contain expected mean tonnages of 5.9 tonnes Au, 210 tonnes Ag, 68,000 tonnes Cu, 100,000 tonnes Pb, 200,000 tonnes Zn, 34,000 tonnes WO_3 and 18 million tonnes Fe in 47 million tonnes of mineralized material. Total mean numbers of expected carbonate-hosted deposits in the Victorio-Tres Hermanas favorable area are 0.6993 polymetallic replacement deposits, 0.3577 replacement manganese deposits, 0.9958 Rio Grande Rift lead-zinc deposits, 1.9673 copper skarn deposits, 0.7130 gold-bearing skarn deposits, 0.8520 zinc-lead skarn deposits, 0.7544 iron skarn deposits, and 0.8778 tungsten skarn deposits. Total expected mean tonnages for all of these deposits are 13 tonnes Au, 1,200 tonnes Ag, 160,000 tonnes Cu, 360,000 tonnes Pb, 470,000 tonnes Zn, 30,000 tonnes Mn, 36,000 tonnes WO_3, and 35 million tonnes Fe contained in 93 million tonnes of mineralized material.

Undiscovered Resources in Carbonate-Hosted Deposits

Analysis of the computer simulation (**table 6-6**, **table 6-7**) shows that the expected mean numbers of undiscovered non-skarn carbonate-hosted deposits in the 14 favorable areas estimated are 3.8239 polymetallic replacement deposits, 13.9778 Rio Grande Rift lead-zinc deposits, and 11.5422 replacement manganese deposits. Of the 14 areas, about 11 are expected to contain no polymetallic replacement deposits. The remaining three areas each contain 1-2 polymetallic replacement deposits. About 6.5 of the 14 areas are expected to contain no replacement manganese deposits; the remaining 7.5 areas each contain 1-4 replacement manganese deposits. More than 4

areas are expected to contain no Rio Grande Rift lead-zinc deposits; the remaining 10 areas each contain 1-3 Rio Grande Rift lead-zinc deposits. Polymetallic replacement deposits, replacement manganese deposits, and Rio Grande Rift lead-zinc deposits account for much of the expected means of Au, Ag, Mn, Pb, and Zn in these undiscovered carbonate-hosted deposits. Expected mean tonnages in these deposits are 19 tonnes Au, 4,800 tonnes Ag, 55,000 tonnes Cu, 1.0 million tonnes Mn, 1,900 tonnes Fe, 1.3 million tonnes Pb, and 1.4 million tonnes Zn; these are about 38 percent of the Au, 83 percent of the Ag, 10 percent of the Cu, 75 percent of the Pb, 60 percent of the Zn, 100 percent of the Mn, and much less than 0.01 percent of the Fe in carbonate-hosted deposits.

Computer simulation using the estimates of undiscovered skarn deposits in the 19 areas favorable for the occurrence of such deposits gives expected means of 4.9127 iron skarn deposits, 2.0916 tungsten skarn deposits, 6.1378 copper skarn deposits, 3.4609 zinc-lead skarn deposits, and 1.8022 gold-bearing skarn deposits. These undiscovered deposits contain expected mean tonnages of 210 million tonnes Fe, 75,000 tonnes WO_3, 31 tonnes Au, 950 tonnes Ag, 480,000 tonnes Cu, 450,000 tonnes Pb, and 920,000 tonnes Zn, contained in 470 million tonnes of mineralized material. Data analysis shows the distribution of expected means of metal tonnages and mineralized material in the different types of skarn deposits. For iron skarn deposits, almost 16 of the favorable areas are expected to have no undiscovered iron skarn deposits, but the remaining three areas may each contain 1-3 deposits. Expected total mean tonnage of undiscovered iron skarn deposits in the study area is 210 million tonnes Fe, contained in 420 million tonnes of mineralized material. All of the iron in undiscovered skarn deposits, and almost 90 percent of the expected mineralized material, is in iron skarn deposits. Tungsten skarn deposits contain 100 percent of the WO_3 in undiscovered skarn deposits --this is the only carbonate-hosted deposit type where tungsten was modeled. An expected mean of 2.0916 tungsten skarn deposits is predicted in the eight areas favorable for their occurrence. About 6 of the eight areas (or 75 percent) are expected to have no tungsten skarn deposits; the remaining two (or 25 percent) may each have 1-3 deposits of this type. An expected mean of 6.1378 copper skarn deposits is predicted for the 19 favorable areas. About 14 of these areas are expected to contain no copper skarn deposits; the remaining 5 could each contain 1-3 undiscovered copper skarn deposits. Expected means of metal amounts in undiscovered copper skarn deposits are 370,000 tonnes Cu, 5.5 tonnes Au, and 46 tonnes Ag, contained in 27 million tonnes of mineralized material.

A mean of 3.4609 undiscovered zinc-lead skarn deposits is expected in the 19 areas favorable for the occurrence of these deposits, with expected mean tonnages of 66,000 tonnes Cu, 11 tonnes Au, 840 tonnes Ag, 450,000 tonnes Pb, and 870,000 tonnes Zn in 15 million tonnes of

mineralized material. Sixteen areas contain no zinc-lead skarn deposits; the remaining 3 areas each contain from 1-3 deposits. Gold-bearing skarn deposits contain about half (or 14 tonnes) of the expected mean gold tonnage in undiscovered skarn deposits. The expected mean number of undiscovered gold-bearing skarn deposits in the 19 favorable areas is 1.8022. According to the statistics, approximately 18 areas have no gold-bearing skarn deposits; the remaining area might contain 1-3 gold-bearing skarn deposits. In addition to gold, skarn deposits contain approximately 67 tonnes Ag, 47,000 tonnes Cu, and 45,000 tonnes Zn in 5.4 million tonnes of mineralized material.

Figure 6-5A-H shows amounts of metals expected in undiscovered carbonate-hosted mineral deposit types in the study area at various levels of probability (or confidence levels). For example, for undiscovered polymetallic replacement deposits (**figure 6-5G**) there is a 90 percent probability that these deposits contain approximately 0.30 tonnes Au, 300 tonnes Ag, 950 tonnes Cu, 100,000 tonnes Zn, and 130,000 tonnes Pb in 2.7 million tonnes of mineralized material. At the 50 percent confidence level, these deposits contain 4.9 tonnes Au, 2,400 tonnes Ag, 20,000 tonnes Cu, 800,000 tonnes Zn, and 730,000 tonnes Pb in 15 million tonnes of mineralized material. At the 10 percent confidence level, these deposits contain 40 tonnes Au, 12,000 tonnes Ag, 130,000 tonnes Cu, 3.5 million tonnes Zn, and 3.0 million tonnes Pb in 58 million tonnes of mineralized material. That is, if there were 100 areas similar to the study area, 90 areas are expected to contain greater than 0.30 tonnes Au, 50 areas are expected to contain greater than 4.9 tonnes Au, and 10 areas are expected to contain greater than 40 tonnes Au. As the confidence level decreases, the expected metals tonnages increase geometrically.

In **figure 6-5H**, for replacement manganese deposits at the 90 percent confidence level, 170,000 tonnes Mn and 260 tonnes Fe are expected in 600,000 tonnes of mineralized material. At the 50 percent confidence level, 16 tonnes Cu, 1,700 tonnes Fe, and 760,000 tonnes Mn are expected in 2.7 million tonnes of mineralized material. At the 10 percent confidence level, 47 tonnes Cu, 3,900 tonnes Fe, and 2.2 million tonnes Mn are expected in 7.3 million tonnes of mineralized material.

METALLIC VEIN DEPOSITS

Metallic deposits here consist of two deposit types--polymetallic veins, and gold-silver-tellurium veins associated with alkalic rocks. These form through hydrothermal activity in rocks other than those that are chiefly carbonate or volcanic rocks. Permissive and nonpermissive tracts and areas favorable for the occurrence of hydrothermal vein deposits are shown in **plate 4**. Much of the study area is permissive for the occurrence of these deposits. The permissive tract includes areas where hydrothermal activity could have taken place. The favorable

areas contain polymetallic vein deposits as well as epithermal vein deposits that may contain base metals.

Eleven tracts in the study area are nonpermissive for hydrothermal vein deposits by gravity, magnetic, and seismic geophysical evidence showing that bedrock is buried beneath more than one km of basin fill. Hydrothermal mineralization may be present at greater depths, but is not considered for this assessment. Twenty-five areas are favorable for the occurrence of hydrothermal vein deposits, based on geological and geophysical evidence suggesting that suitable host rocks are within one km of the surface; other evidence includes mining districts or past mining activity and geochemical anomalies in stream-sediment samples. The favorable areas are discussed below.

Using current geological, geophysical, and geochemical information and information on the mineral occurrences in the study area and adjacent to it, the assessment team estimated the numbers of undiscovered polymetallic vein deposits and gold-silver-tellurium vein deposits associated with alkalic rocks at the 90, 50, 10, 5, 1, 0.5, and 0.1 percent confidence levels (probabilities) (**table 6-8**, **table 6-9**).

Areas Favorable for the Occurrence of Metallic Vein Deposits

Alum Mountain Favorable Area

Alum Mountain favorable area includes Alum Mountain mining district that covers most of the area. It was selected as being favorable for the occurrence of polymetallic veins owing to the presence of hydrothermal alteration in the volcanic rocks along the south edge of Gila caldera. Also, identified pyrite may be indicative. The area lies on the edge of a magnetic high and overlies a gravity low. Geochemical anomalies of Ba, Co, Cr, Cu, Mn, Mo, Nb, Pb, Th, and Ti, and scattered Be and Y are recognized in stream-sediment samples. Aeroradiometric U and Th anomalies are recognized in the region. Estimates of undiscovered hydrothermal vein deposits in the study area are shown in (**table 6-8**). The assessment team estimated a one percent probability of one undiscovered polymetallic vein deposit, a 0.5 percent probability of 2 such deposits, and a 0.1 percent probability of 2 or more such undiscovered deposits. Results of the computer simulation using the estimates show a 97 percent probability of no undiscovered polymetallic veins , a 2.25 percent probability of one deposit and a 0.75 percent probability of 2 or more such deposits. The mean number of deposits expected is 0.0374. Expected means of metal tonnages are 0.012 tonnes Au, 4.7 tonnes Ag, 3.3 tonnes Cu, 250 tonnes Pb, and 260 tonnes Zn, contained in 4,500 tonnes of mineralized material.

Apache Favorable Area

Apache favorable area includes Apache No. 2 and Fremont mining districts and surrounding areas in the Sierra Rica along the New Mexico-Mexico border. These districts have known epithermal and carbonate-hosted mineralization and are in an area favorable for the occurrence of porphyry copper mineralization. They lie along a northwest trend paralleling the Texas lineament and on gravity and a regional magnetic highs. Estimates of the numbers of undiscovered hydrothermal vein deposits are shown in **table 6-8**. Results of the computer simulation using the estimates show a 91.25 percent probability of no undiscovered polymetallic veins and a 8.75 percent probability of one or more such deposits. The mean number of deposits expected is 0.1770. Expected means of metal tonnages (**table 6-9**) are 0.055 tonnes Au, 15 tonnes Ag, 24 tonnes Cu, 1,200 tonnes Pb, and 1,100 tonnes Zn contained in 21,000 tonnes of mineralized material.

Burro Mountains Favorable Area

Burro Mountains favorable area extends northwestward from southeast of the White Signal mining district to beyond the Black Hawk district, where it adjoins the San Francisco-Steeple Rock-Caprock favorable area. Along with Black Hawk and White Signal districts, Malone, Burro Mountains, and Telegraph mining districts are included. The area contains Precambrian rocks exposed in the Burro Mountains, and follows a gravity high outlining them. Other evidence for the presence of undiscovered metallic vein mineral deposits is the occurrence of Tyrone stock and Tyrone open-pit mine. Geochemical anomalies of Ag, Ba, Cr, Cu, K, Mn, Mo, Nb, Pb, Sn, Th, Ti, and Zn were identified in stream-sediment samples, and aeroradiometric Th and U highs and a K low occur. Results of the computer simulation using the estimates of undiscovered metallic mineral deposits show a 20.4 percent probability of no undiscovered polymetallic veins, a 19.6 percent probability of one deposit, a 52.8 percent probability of 2 deposits, and a 7.2 percent probability of 3 or more polymetallic vein deposits. The mean number of deposits expected is 1.4673. Expected means of metal tonnages are 0.47 tonnes Au, 130 tonnes Ag, 200 tonnes Cu, 11,000 tonnes Pb, and 7,900 tonnes Zn contained in 150,000 tonnes of mineralized material.

Carrizalillo Favorable Area

Carrizalillo favorable area is northwest-trending, approximately paralleling the strike of the Cedar Mountains near the New Mexico-Mexico border. The area includes Carrizalillo mining district, where small amounts of epithermal mineralization are identified. Geochemical and geophysical anomalies may be evidence of undiscovered mineral deposits. The district lies in gravity and magnetic lows and occurs southeast of a gravity high. Stream-sediment samples have indicated geochemical anomalies of As, Ba, La, Sb, Th, and Y. A Cd anomaly surrounds the

district, and Cr and Mn are anomalous at the south end of the district. Estimates of the probabilities of undiscovered polymetallic vein deposits in the Carrizalillo area are shown in **table 6-8**. Results of the computer simulation show a 97 percent probability of no undiscovered polymetallic veins, a 2.25 percent probability of one deposit, and a 0.75 percent probability of 2 or more deposits. The expected mean number of polymetallic vein deposits is 0.0448. Expected means of metal tonnages are 0.014 tonnes Au, 3.5 tonnes Ag, 3.9 tonnes Cu, 260 tonnes Pb, and 280 tonnes Zn contained in 4,100 tonnes of mineralized material.

Cora Miller Favorable Area

Cora Miller favorable area was determined to be favorable for the occurrence of polymetallic vein deposits, because it contains Cora Miller mining district, which has produced small amounts of material from epithermal veins (North and McLemore, 1986). The district lies along the eastern edge of the Schoolhouse Mountain caldera, a potential source of heat, fluids, and fractures necessary for formation of the vein deposits. Geophysical evidence includes linked, semi-circular magnetic highs, which could indicate caldera borders, ring-fracture intrusions, or contrasts between caldera wall and moat rocks. Linear magnetic lows over mid-Tertiary volcanic rocks with a nearby magnetic high indicate areas of altered fault zones that may host mineral deposits. Geochemical anomalies of La, Mn, Mo, Nb, Sn, and Y and spot anomalies of Be, Co, Cr, Cu, K, and U are found in stream-sediment samples and may be indicative of mineralization along the caldera wall.

Estimates of the probabilities of undiscovered polymetallic vein deposits in the Cora Miller favorable area are shown in **table 6-8**. Computer simulation using the team estimates shows there is a 92.5 percent probability of no undiscovered polymetallic veins and a 7.5 percent probability of one or more such deposits. The mean number of deposits expected is 0.1090. Expected means of metal tonnages are 0.037 tonnes Au, 12 tonnes Ag, 15 tonnes Cu, 890 tonnes Pb, and 600 tonnes Zn contained in 12,000 tonnes of mineralized material **table 6-9**.

Doña Ana Mountains Favorable Area

Doña Ana Mountains favorable area comprises a small area within Doña Ana caldera. The area includes the Doña Ana Mountains and Doña Ana mining district. Geophysical data shows a gravity high encircling the northwest side of the caldera, and a magnetic high that is probably caused by an intrusion within the caldera. Gravity and magnetic highs coincide in the area. Geochemical anomalies of As, Be, Co, La, Nb, Th, Ti, and U are found in stream-sediment samples. Surface rocks consist of sedimentary carbonate, volcanic, and intrusive rocks. Estimates of the probabilities of undiscovered polymetallic vein deposits in the Doña Ana Mountains favorable area are shown in **table 6-8**. Computer simulation shows a 97 percent probability of no

undiscovered polymetallic veins and a 3 percent probability of one or more such deposits. The mean number of deposits expected is 0.0312. Expected means of metal tonnages are 0.0039 tonnes Au, 1.4 tonnes Ag, 1.3 tonnes Cu, 150 tonnes Pb, and 150 tonnes Zn contained in 3,200 tonnes of mineralized material.

Florida Mountains Favorable Area

Florida Mountains favorable area includes the Florida and Little Florida Mountains and some of the surrounding plain. The outline of the area follows a gravity high underlying the area. Included are the Florida Mountains and Little Florida mining districts, which contain known hydrothermal and epithermal mineralization. Geochemical anomalies of Ba, Be,Co, Cu, K, La, Mn, Nb, Pb, Sb, Sn, Th, Y, Zn, and spot Bi, Cd, Mo, and Ti occur in stream-sediment samples in drainages from the Little Florida Mountains. Estimates of the probabilities of undiscovered polymetallic vein deposits in the Florida Mountains favorable area are shown in **table 6-8**. Results of computer simulation using the estimates show a 99.1 percent probability of no undiscovered polymetallic veins, a 0.3 percent probability of one such deposits, and a 0.6 percent probability of 2 or more deposits. The mean number of deposits expected is 0.0154. Expected means of metal tonnages are 0.010 tonnes Au, 0.70 tonnes Ag, 3.4 tonnes Cu, 150 tonnes Pb, and 95 tonnes Zn contained in 1,900 tonnes of mineralized material.

Fluorite Ridge Favorable Area

Fluorite Ridge favorable area is delineated by the presence of epithermal mineralization in Fluorite Ridge mining district and, using seismic data, by recognition that about 200 m of volcanic rock overlies bedrock that may host hydrothermal veins. The area is located along a gravity high; a magnetic high lies to the northwest. Geochemical stream-sediment anomalies of As, Ba, Cd, Cr, Cu, La, Mn, Mo, Pb, Ti, and Zn are reported. Tertiary granodiorite intrudes Paleozoic limestone and is capped by late Tertiary conglomerate. Epithermal fluorite veins were formed after deposition of the conglomerate. Results of the computer simulation using team estimates show there is a 99.7 percent probability of no undiscovered polymetallic veins and only a 0.3 percent probability of one or more such deposits. The mean number of deposits expected is 0.0028. Expected means of metal tonnages are 0.000087 tonnes Au, 0.096 tonnes Ag, 0.049 tonnes Cu, 18 tonnes Pb, and 6.0 tonnes Zn contained in 170 tonnes of mineralized material.

Gila Fluorspar Favorable Area

Gila Fluorspar favorable area is nearly coincident with, although slightly larger than, Gila Fluorspar mining district. The area was selected for the occurrence of undiscovered polymetallic veins, owing to the presence of hydrothermally altered volcanic rocks and known mineral occurrences. The area overlies a magnetic high and is on a gravity gradient. An aeroradiometric U

high and an offset Th low may be indicative of hydrothermal alteration. Geochemical anomalies of Ag, Ba, Co, Cu, Mn, Mo, Nb, Pb, Y, and Zn occur. Estimates of undiscovered hydrothermal mineral deposits are shown in **table 6-8**. Results of the computer simulation using estimates of undiscovered hydrothermal mineral deposits show a 97 percent probability that no undiscovered polymetallic veins are present, a 2.25 percent probability of one deposit, and a 0.75 percent probability of 2 or more deposits. The mean number of deposits expected is 0.0356. Expected means of metal tonnages are 0.0027 tonnes Au, 2.3 tonnes Ag, 0.77 tonnes Cu, 220 tonnes Pb, and 190 tonnes Zn contained in 3,400 tonnes of mineralized material.

Gillespie Favorable Area

The boundary of the Gillespie favorable area parallels the eastern part of Gillespie mining district where epithermal fluorite veins occur. The area includes Gillespie and Red Hill mines. Juniper, Animas Peak, Tullous, and Cowboy Rim calderas are proximal to one another within the favorable area. Low-amplitude gravity and magnetic highs underlie the area, and aeroradiometric lows for K, U, and Th occur. Geochemical anomalies of Ag, Be, Co, K, La, Mn, Nb, Th, U, and Y are present as are spot anomalies of Sn and Ti. A gold anomaly is present at Athena fluorite mine. Estimates of undiscovered polymetallic vein deposits in the Gillespie favorable area are shown in **table 6-8**. Results of the computer simulation using the estimates show there is a 97 percent probability that there are no undiscovered polymetallic veins, a 2.25 percent probability of one deposit, and a 0.75 percent probability of 2 or more deposits. The mean number of deposits expected is 0.0370. Expected means of metal tonnages are 0.0035 tonnes Au, 2.1 tonnes Ag, 1.1 tonnes Cu, 210 tonnes Pb, and 160 tonnes Zn contained in 3,200 tonnes of mineralized material (**table 6-9**).

Gold Hill Favorable Area

Gold Hill favorable area was delineated, in part, on the basis of exposed Precambrian rocks. The area includes Bound Ranch and Gold Hill mining districts where polymetallic veins as well as other types of mineral deposits occur. Geochemical anomalies for Ag, Be, Co, Cr, K, La, Mn, Mo, Nb, Pb, Th, Ti, U, Y, and Zn are present in stream-sediment samples. The area is part of the Santa Rita trend and lies along a northwest-trending magnetic high and a gravity low. The magnetic high occurs on a gravity gradient. Aeroradiometric U and Th highs are present; U is high near Bound Ranch. Team estimates of undiscovered hydrothermal mineral deposits are shown in **table 6-8**. Computer simulation using the estimates determined a 30 percent probability of no undiscovered polymetallic veins , a 67 percent probability of one deposit, a 2.25 percent probability of 2 deposits, and a 0.75 percent probability of 3 or more deposits. The mean number of deposits expected is 0.7481. Expected means of metal tonnages are 0.21 tonnes Au, 84 tonnes

Ag, 110 tonnes Cu, 6,400 tonnes Pb, and 4,500 tonnes Zn contained in 88,000 tonnes of mineralized material.

Little Hatchet Favorable Area

Little Hatchet favorable area includes Eureka and Sylvanite mining districts, the Little Hatchet Mountains, and surrounding alluvial plain. The mining districts include carbonate-hosted vein, replacement, and skarn deposits; gold-placer sands suggest areas where additional undiscovered mineral deposits may occur. At Winkler Ranch in the southern part of the area, tungsten prospects are known. Geochemical anomalies of As, Cd, Co, Cu, Mn, Mo, and spot Sb are present in Sylvanite district. At the south end of that district, Be, Bi, K, La, Nb, U, and Y anomalies are present. As, Cd, and Co, and a spot anomaly of Sb occur within Eureka district, and Mn is anomalous at the east end of that district. Distinctive aeroradiometric K, U, and Th anomalies (with slight U enrichment) indicative of the presence of carbonate rocks are seen in both districts.

Estimates of undiscovered polymetallic vein deposits in the Little Hatchet favorable area are shown in **table 6-8**. Results of the MARK-3 computer simulation using the estimates show there is a 70 percent probability of no undiscovered polymetallic veins, a 22.5 percent probability of one deposit, a 6.75 percent probability of 2 deposits, and a 0.75 percent probability of 3 or more such deposits. The mean number of deposits expected is 0.3777. Expected means of metal tonnages are 0.010 tonnes Au, 40 tonnes Ag, 54 tonnes Cu, 3,500 tonnes Pb, and 2,200 tonnes Zn, contained in 45,000 tonnes of mineralized material.

Lordsburg Favorable Area

To delineate Lordsburg favorable area, the outline of Lordsburg mining district was used as the starting point, but was expanded to include the northern part of the Pyramid Mountains. The area was outlined by the presence of the mining district and its mineral occurrences, and by magnetic and gravity highs that may indicate a significant thickness of silicified and oxidized volcanic rock. Lordsburg district coincides with the Santa Rita trend of porphyry deposits, and recent exploratory drilling in search of mineralization in rhyolite plugs has taken place. Large faults mapped in the area may have acted as conduits for mineralizing fluids. Known mineral deposits include polymetallic veins, with fluorite as a byproduct. The veins are rich in silica, which is mined to be used as flux in copper smelters. The value of the precious metals in the silica ore is profit for the miner. Aeroradiometric K, U, and Th are undistinguished. Geochemical anomalies in the mining district are Ag, Be, Co, Cr, Cu, Mo, Pb, Ti, and spot Sn. Ba is scattered from north to south, Y is anomalous to the northwest, and Th is anomalous in the northern and southern parts of the district.

Estimates of undiscovered hydrothermal mineral deposits in the Lordsburg favorable area are shown in **table 6-8**. Results of the MARK-3 computer simulation using the estimates show there is a 6.67 percent probability of no undiscovered polymetallic veins, a 23.33 percent probability of one deposit, a 62.5 percent probability of 2 deposits, a 6.75 percent probability of 3 deposits, a 0.45 percent probability of 4 deposits, and a 0.3 percent probability of 5 or more deposits. The mean number of deposits expected is 1.7177. Expected means of metal tonnages are 0.047 tonnes Au, 200 tonnes Ag, 200 tonnes Cu, 15,000 tonnes Pb, and 9,700 tonnes Zn contained in 200,000 tonnes of mineralized material.

Lordsburg Mesa Favorable Area

Lordsburg Mesa favorable area has few visible surficial clues to possible mineralization and contains no resident mining districts or known mineral occurrences. Delineation of the area is by the presence of a remotely sensed zone of limonitic alteration (Raines and others, 1985). The alteration zone is correlated with a U anomaly, and the area is on the same gravity and magnetic ridges as the Lordsburg area. An aeroradiometric K anomaly peripheral to the limonitic alteration zone is evidence of erosion and transportation of radioactive elements. Geochemical anomalies of samples taken in alluvium covering the area may not be representative of the rocks or mineralization --the anomalous minerals may have been derived some distance up-drainage. Using estimates of undiscovered polymetallic vein hydrothermal deposits, results of the MARK-3 computer simulation indicate there is a 99.7 percent probability of no undiscovered polymetallic veins and only a 0.3 percent probability of one or more deposits. The mean number of deposits expected is 0.0034. Expected means of metal tonnages are 0.0012 tonnes Au, 0.11 tonnes Ag, 0.30 tonnes Cu, 37 tonnes Pb, and 16 tonnes Zn contained in 440 tonnes of mineralized material.

Old Hadley Favorable Area

Old Hadley favorable area was delineated by location of the Old Hadley mining district, the occurrence of Paleozoic rocks, and by epithermal deposits. Geochemical stream-sediment anomalies of Ag, As, Bi, Cd, Mo, Pb, Sb, Th, and Zn are reported, and anomalies of K, Sn, and U surround the area. The area lies on the edge of a magnetic high; no gravity anomalies were noted. Estimates for the occurrence of undiscovered polymetallic vein deposits are shown in **table 6-8**. Computer simulation using the estimates indicates a 97 percent probability of no undiscovered polymetallic veins and a 2.25 percent probability of one deposits, and a 0.75 percent probability of 2 or more deposits. The mean number of deposits expected is 0.0382. Expected

means of metal tonnages are 0.0056 tonnes Au, 6.3 tonnes Ag, 1.4 tonnes Cu, 360 tonnes Pb, and 210 tonnes Zn contained in 4,800 tonnes of mineralized material.

Organ Mountains Favorable Area

Organ Mountains favorable area includes Organ Mountains mining district and the southwestern third of Black Mountain mining district. Delineation of the area is based on the location of Organ Mountains mining district, associated mineral deposits, and a steep gravity gradient on the east and northwest boundaries. The southern boundary includes mineral occurrences near Bishop Cap.

Organ Mountains mining district is within a gravity low extending to Organ Peak that is associated with intrusion of the Organ batholith. Plutons contain disseminated pyrite at various locations, and argillic and sericitic alteration are pervasive; the gravity low may be caused by sericitic alteration. Aeroradiometric K, U, and Th are elevated.

Gravity and magnetic highs extend southward from Bishop Cap; they may be the result of a series of intrusions at some depth and could be associated with skarn formation. Bishop Cap area has a distinct aeroradiometric U/K, and U/Th is relatively high. Geochemical analysis of stream-sediment samples shows that there are coincident Be, Cu, Mn, Mo, Pb, and Zn anomalies on the east side of the Organ Mountains. Nb and Ti are anomalous on the southern edge of the mountains, and La is anomalous on the east side of the mountains near Organ. As, Bi, Cd, and U are anomalous throughout the area. Exploratory drilling for a porphyry copper deposit north of the town of Organ is a positive indication of the potential for polymetallic vein deposits.

This area is one of four areas having a 90 percent probability of one polymetallic vein deposit. Using the estimates, the MARK-3 program computed an expected mean of 1.6939 polymetallic vein deposits. Computer simulation using the estimates shows a 6.67 percent probability of no deposits, a 23.33 percent probability of one deposit, a 62.5 percent probability of 2 deposits, and a 7.5 percent probability of 3 or more deposits. Expected means of metal tonnages are 0.47 tonnes Au, 180 tonnes Ag, 180 tonnes Cu, 14,000 tonnes Pb, and 10,000 tonnes Zn contained in 200,000 tonnes of mineralized material. This area is the only area favorable for the occurrence of Au-Ag-Te veins associated with alkalic rocks, owing to the presence of alkalic rocks, and recognition that locally the veins, like that at the Hilltop mine, contain Te minerals. The team estimated a 10 percent probability of one Au-Ag-Te vein deposit, a 5 percent probability of 2 such deposits, and a one percent probability of 3 or more such deposits. Results of the MARK-3 computer simulation using the team estimates indicate a 70 percent probability of no undiscovered Au-Ag-Te vein deposits, a 22.5 percent probability of one deposit, a 4.5 percent probability of 2 deposits, and a 3 percent probability of 3 or more deposits. The mean number of deposits

expected is 0.3969. Expected means of metal tonnages in undiscovered Au-Ag-Te veins are 44 tonnes Au and 18 tonnes Ag contained in 6.6 million tonnes of mineralized material.

Combining the expected mean tonnages of metals in undiscovered metallic vein deposits in the Organ Mountains favorable area shows that the total tonnages are 45 tonnes Au, 200 tonnes Ag, 180 tonnes Cu, 14,000 tonnes Pb, and 10,000 tonnes Zn, contained in 6.8 million tonnes of mineralized material. The probable tonnage of undiscovered resources in Au-Ag-Te veins overwhelms the probable tonnages of gold and mineralized material in polymetallic veins. Au-Ag-Te veins account for almost 99 percent of the Au, over 9 percent of the Ag, none of the Cu, Pb, and Zn, and over 97 percent of the mineralized material.

Peloncillo Favorable Area

Delineation of the Peloncillo favorable area is based upon the north-northwest trend of the Peloncillo Mountains, where favorable rocks are exposed along the western border of the study area. Granite Gap, McGhee Peak, and Kimball mining districts within the Peloncillo favorable area contain carbonate-hosted and epithermal vein deposits, have had considerable past base-metals production, and may have considerable undiscovered mineral resources. Kimball district lies on a gravity gradient; Granite Gap and McGhee Peak districts coincide with a gravity high. The latter two districts are on or near the edges of magnetic highs; Kimball district is outside of the magnetic data coverage. Kimball district is relatively higher in aeroradiometric K and U. Geochemical anomalies of Ag, Cu, and Sn, and spot anomalies of Be, Bi, Cr, La and Mn occur in stream-sediment samples. Estimates of the number of undiscovered polymetallic vein deposits are shown in **table 6-8**. Computer simulation using the estimates indicates a 97 percent probability of no undiscovered polymetallic veins, a 2.25 percent probability of one deposit, and a 0.75 percent probability of 2 or more deposits. The mean number of deposits expected is 0.0360. Expected means of metal tonnages are 0.0078 tonnes Au, 1.1 tonnes Ag, 7.2 tonnes Cu, 170 tonnes Pb, and 160 tonnes Zn contained in 3,200 tonnes of mineralized material.

Piños Altos-Santa Rita Favorable Area

Piños Altos-Santa Rita favorable area contains Bayard, Chloride Flat, Copper Flat, Fierro-Hanover, Fleming, Georgetown, Lone Mountain, Piños Altos, and Santa Rita mining districts. These districts have had considerable past production and contain many mineral deposits, including such major deposits as the Santa Rita porphyry copper deposit, the Continental copper skarn deposits, Fierro-Hanover iron skarn deposits, and the Piños Altos skarn deposits. The area is delineated to include these districts and all deposits between them. Reasoning for delineation of the favorable area includes the existence of phyllic and potassic alteration, widespread pyritization, the presence of calc-alkaline intrusive rocks, and the widespread occurrence of known base-metal

veins. Three magnetic highs are recognized, and aeroradiometric U and K highs are present along the edges of the magnetic highs. Geochemical anomalies for metals such as Ag, Be, Cu, Mo, Pb, and W are seen in stream-sediment samples. Copper is especially common.

Estimates of polymetallic vein deposits are shown in **table 6-8**. The estimates range from a 90 percent probability of one undiscovered deposit, to a one percent probability of 3 such deposits. Results of the computer simulation using the estimates indicate there is a 6.67 percent probability of no undiscovered polymetallic veins, a 63.33 percent probability of one deposit, a 27 percent probability of 2 deposits, and a 3.0 percent probability of 3 or more deposits. The mean number of deposits expected is 1.2583. Expected means of metal tonnages are 0.38 tonnes Au, 110 tonnes Ag, 180 tonnes Cu, 9,700 tonnes Pb, and 7,100 tonnes Zn contained in 140,000 tonnes of mineralized material.

Rincon Favorable Area

Delineation of the Rincon favorable area is based on the presence of Rincon mining district, which is the site of minor carbonate-hosted and epithermal manganese mineral deposits. The area lies on a gravity high and on a magnetic low north of the Juniper caldera. Geochemical anomalies of Ag, Be, La, Mo, Nb, Pb, Sn, Th, and U are present in drainages. Aeroradiometric K, U, and Th are undistinguished. Estimates of undiscovered polymetallic vein deposits are shown in **table 6-8**. Results of the MARK-3 computer simulation using the estimates show that the Rincon area is one of the least likely areas for the occurrence polymetallic vein mineralization. There is a 99.7 percent probability of no undiscovered polymetallic veins and a 0.3 percent probability of one or more deposits. The mean number of deposits expected is 0.0024. Expected means of metal tonnages are 0.00018 tonnes Au, 0.014 tonnes Ag, 0.16 tonnes Cu, 6.3 tonnes Pb, and 1.6 tonnes Zn contained in 28 tonnes of mineralized material.

San Andrecito-Hembrillo Favorable Area

Delineation of the San Andrecito-Hembrillo favorable area for the occurrence of polymetallic vein deposits is based on the presence of San Andrecito-Hembrillo mining district, where talc, base- and precious-metal vein and replacement, and barite-fluorite deposits occur; Cambrian through Cretaceous sedimentary rocks, including the Lead Camp Limestone and the Bliss Sandstone that host hydrothermal mineralization; and Cd, Cr, Nb, Sn, Sb, Th, and Y geochemical anomalies.

Results of the MARK-3 computer simulation based on estimates show a 56.67 percent probability of no undiscovered polymetallic veins, a 13.33 percent probability of 1-2 deposits, and a 16.67 percent probability of 3 or more deposits. The mean number of deposits expected is 0.8882. Expected means of metal tonnages are 0.24 tonnes Au, 86 tonnes Ag, 99 tonnes Cu, 710

tonnes Pb, and 4,800 tonnes Zn contained in 98,000 tonnes of mineralized material.

San Francisco-Steeple Rock-Caprock Favorable Area

San Francisco-Steeple Rock-Caprock favorable area was delineated by the location of San Francisco, Steeple Rock, and Caprock mining districts, and is coincident with a northwest-trending gravity gradient. Numerous geochemical anomalies occur in the area. In Steeple Rock district, for example, anomalies of Ag, Ba, Co, Cr, Cu, K, La, Mn, Mn, Nb, Pb, Th, Ti, Y, and Zn occur in stream-sediment samples, whereas San Francisco district has anomalies of Ag, Cu, Pb, and Zn, and Caprock district is anomalous in Ag, Co, Cu, La, Mn, Sn, Th, Ti, and Y. The Hells Hole porphyry system influences geochemical anomalies in the Steeple Rock area. This favorable area is one of four where estimates show a 90 percent probability of one polymetallic vein deposit, a 10 percent probability of 2 deposits, and a one percent probability of 3 deposits. Computer simulation using the team estimates of undiscovered polymetallic vein deposits indicate a 6.67 percent probability of no undiscovered polymetallic veins, a 63.33 percent probability of one deposit, a 27 percent probability of 2 deposits, and a 3 percent probability of 3 or more deposits. The mean number of deposits expected is 1.2667. Expected means of metal tonnages are 0.34 tonnes Au, 120 tonnes Ag, 140 tonnes Cu, 10,000 tonnes Pb, and 6,900 tonnes Zn contained in 140,000 tonnes of mineralized material.

Silvertip Favorable Area

Delineation of Silvertip favorable area is based on the location of Silvertip mining district and recognition of an area north of the district along the rim of the Geronimo Trail caldera where a magnetic high indicates a probable igneous intrusion into the caldera wall. A gravity gradient delineates the caldera boundary and fault zone. Aeroradiometric U and Th highs outline the caldera wall. A geochemical anomaly of Nb occurs in the northern part of the area, and Be, Co, Cu, Pb, Mo, Mn, and Zn anomalies exist in the area.

Team estimates indicate a one percent probability of 2 undiscovered polymetallic vein deposits. Results of the MARK-3 computer simulation using the estimates show a 96 percent probability of no undiscovered polymetallic veins, a 2 percent probability of one deposit, and a 2 percent probability of 2 or more deposits. The mean number of deposits expected is 0.0596. Expected means of metal tonnages are 0.0077 tonnes Au, 4.2 tonnes Ag, 2.4 tonnes Cu, 460 tonnes Pb, and 310 tonnes Zn contained in 5,700 tonnes of mineralized material.

Tres Hermanas Favorable Area

Tres Hermanas favorable area is delineated by the Tres Hermanas mining district and its constituent carbonate-hosted and other types of mineral occurrences. The favorable area boundary from the district boundary southeastward to the New Mexico-Mexico border parallels a gravity

high that underlies much of southern Luna County. Seismic data indicates that east of the mining district along the gravity high, bedrock occurs at depths of less than one km. Geochemical anomalies from stream-sediment samples include As, Ba, Be, Co, K, La, Mn, Mo, Pb, Sb, Th, Y, and Zn; Cr is anomalous at the southern end of the mining district.

Results of the MARK-3 computer simulation using the team estimates of undiscovered polymetallic vein deposits show a 60 percent probability of no undiscovered polymetallic veins, a 20 percent probability of one deposit, a 12.5 percent probability of 2 deposits, and a 7.5 percent probability of 3 or more deposits (**table 6-8**). The expected mean number of undiscovered polymetallic vein deposits is 0.6311. Expected means of metal tonnages are 0.17 tonnes Au, 63 tonnes Ag, 0.49 tonnes Cu, 5,300 tonnes Pb, and 3,700 tonnes Zn contained in 74,000 tonnes of mineralized material (**table 6-9**).

Victorio Favorable Area

Victorio favorable area boundary parallels the outline of a gravity high that underlies the area. Seismic data indicates that the anomaly probably represents carbonate rocks, which may host undiscovered polymetallic vein and other mineral deposits, buried at a depth of less than 500-800 m. The area includes Victorio mining district, where considerable past mineral production took place, mainly from carbonate-hosted mineral deposits. The area includes part of the Texas lineament south of the Burro Uplift. Geochemical anomalies of Co, Mn, Pb, and Zn, and spot anomalies of Bi and La occur in stream-sediment samples. A distinct aeroradiometric K, U, and Th anomaly is recognized as being indicative of a slight enrichment of U, as well as mineralized carbonate rock.

Estimates of a 10 percent probability of one undiscovered polymetallic vein deposit and a 5 percent probability of 2 deposits indicate low potential. Results of the MARK-3 computer simulation show a 70 percent probability of no undiscovered polymetallic veins, a 22.5 percent probability of one deposit, a 4.5 percent probability of 2 deposits, and a 3 percent probability of 3 or more deposits. The mean number of deposits expected is 0.3875. Expected means of metal tonnages are 0.10 tonnes Au, 45 tonnes Ag, 44 tonnes Cu, 3,500 tonnes Pb, and 2,300 tonnes Zn contained in 45,000 tonnes of mineralized material.

Wilcox Favorable Area

Wilcox favorable area is delineated by the southern rim of Bursum caldera (Elston and others, 1976) and on geophysical data. The southern tip of Wilcox mining district is included, with its constituent fluorite veins and other deposit types. The area is on the edge of Mangus graben, and local mineralization may be related to it. A faint gravity high is aligned along the graben, and the area overlies a magnetic high and a gravity low. Geochemical anomalies of Ag,

Be, Cr, Cu, K, Mn, Th, Ti, Y, and Zn and spot anomalies of Mn and U occur in stream-sediment samples from the district.

Estimates of undiscovered polymetallic vein deposits show that this area has the lowest potential of any area favorable for metallic vein deposits. Results of the MARK-3 computer simulation using the estimates indicate a 97 percent probability of no undiscovered polymetallic veins, a 2.25 percent probability of one deposit, and a 0.75 percent probability of 2 or more deposits. The mean number of deposits expected is 0.0380. Expected means of metal tonnages are 0.0061 tonnes Au, 4.3 tonnes Ag, 4.3 tonnes Cu, 360 tonnes Pb, and 240 tonnes Zn contained in 4,600 tonnes of mineralized material.

Undiscovered Resources in Metallic Vein Deposits

Results of the computer simulation confirm that while polymetallic vein deposits occur in significant numbers, they are usually rather small and their amounts of precious and base metals are rather insignificant on a regional scale. Team estimates produced an expected mean of 11.1043 polymetallic vein deposits in the 25 favorable areas. These deposits contain expected means of 3.1 tonnes Au, 1,100 tonnes Ag, 1,300 tonnes Cu, 90,000 tonnes Pb, and 63,000 tonnes Zn contained in 1.2 million tonnes of mineralized material. In the study area, these totals are less than one percent of the Au, Cu, Pb, and Zn, and 3 percent of the expected mean Ag. In contrast, the larger, but less numerous, Au-Ag-Te veins contain much more gold. The estimate for the occurrence of Au-Ag-Te veins in one area produced an expected mean of 0.3969 deposits, containing 44 tonnes Au and 18 tonnes Ag, contained in 6.6 million tonnes of mineralized material. This estimate is about 8.4 percent of the Au expected to occur in undiscovered deposits in the study area.

Figure 6-7A presents the amounts of metals expected in undiscovered polymetallic vein mineral deposit types in the study area at various confidence (probability) levels. For undiscovered polymetallic vein deposits, there is a 90 percent probability that these deposits contain approximately 0.059 tonnes Au, 99 tonnes Ag, 20 tonnes Cu, 4,500 tonnes Zn, and 14,000 tonnes Pb in 190,000 tonnes of mineralized material. At the 50 percent confidence level, these deposits contain 0.71 tonnes Au, 450 tonnes Ag, 210 tonnes Cu, 30,000 tonnes Zn, and 56,000 tonnes Pb in 850,000 tonnes of mineralized material. At the 10 percent confidence level, these deposits contain 8.7 tonnes Au, 2,700 tonnes Ag, 2,500 tonnes Cu, 170,000 tonnes Zn, and 200,000 tonnes Pb contained in 2.9 million tonnes of mineralized material. For Au-Ag-Te veins at confidence levels greater than 25 percent, there are no undiscovered resources (**figure 6-7B**). At the 20 percent confidence level, these deposits contain 6.2 tonnes Au, and 2.1 tonnes Ag, contained in 620,000 tonnes of mineralized material. That is, if 5 areas having geological and

geophysical characteristics similar to the study area were explored, one area would be expected to have those tonnages of metals and equal or greater amounts of mineralized material in undiscovered Au-Ag-Te veins. At the 10 percent confidence level, the study area contains 43 tonnes Au and 30 tonnes Ag contained in 15 million tonnes of mineralized material.

Small tonnages are expected in areas favorable for undiscovered polymetallic vein deposits (**table 6-9**). Organ Mountains favorable area has the most tonnage; it may host both Au-Ag-Te vein deposits and polymetallic vein deposits. The remaining 24 areas are expected to contain only polymetallic veins. Of these, the Lordsburg favorable area is expected to have the largest mean tonnage (200,000 tonnes of mineralized material). Burro Mountains, San Francisco-Caprock, and Piños Altos-Santa Rita areas contain 150,000 tonnes, 140,000 tonnes, and 140,000 tonnes, respectively. The remaining 20 areas have expected tonnage means of less than 100,000 tonnes. Ten of these contain expected means of 1,000-10,000 tonnes of mineralized material, and 3 areas contain expected means of less than 1,000 tonnes of mineralized material.

EPITHERMAL VEIN DEPOSITS

Epithermal vein deposits, such as quartz-adularia and quartz-alunite gold-silver veins, epithermal manganese, and sediment-hosted gold, form in terranes having felsic to intermediate volcanic and subvolcanic rocks. Alteration and faulting allow warm fluids to access the rocks, and provide voids in which minerals may form. At the relatively large scale of the assessment, small-scale faults and localized alteration are not known with certainty. Many epithermal vein mineral deposits are present, or may occur, in several mining districts, mainly in the western part of the study area.

All of the study area is permissive for the occurrence of epithermal vein deposits, with the exception of deep basins. San Andres Mountains lack the volcanic activity necessary for the formation of epithermal vein deposits. **Plate 5** shows the location of the permissive tract, nonpermissive tracts, and areas favorable for epithermal vein deposits.

The permissive tract is delineated by accumulations of intermediate to felsic rocks and Tertiary eruptive centers, such as the Mogollon-Datil volcanic field in Grant County. Geophysical anomalies indicating the potential for buried intrusions beneath the volcanic rocks that may have promoted mineralization are considered positive for the presence of epithermal systems. Areas lacking accumulations of felsic to intermediate volcanic rocks on the surface or within one km of the surface form the nonpermissive tracts. Favorable areas are discussed below.

Using geological, geophysical, and geochemical information presented herein, as well as information on the mineral occurrences in the study area and adjacent to it, the assessment team estimated the numbers of undiscovered deposits of quartz-adularia veins, quartz-alunite veins,

epithermal manganese, and sediment-hosted gold at the 90, 50, 10, 5, 1, 0.5, and 0.1 percent confidence levels (**table 6-10**). Expected mean tonnages of metals in epithermal vein deposits are shown in **table 6-11**.

Areas Favorable for the Occurrence of Epithermal Deposits

Alum Mountain Favorable Area

Alum Mountain favorable area includes Alum Mountain mining district and is one of four areas favorable for the occurrence of both quartz-adularia and quartz-alunite gold-silver veins. The area lies on the edge of a magnetic high along the south edge of Gila caldera. Geochemical anomalies of Ba, spot Be, Co, Cr, Cu, Mn on the north end of the mining district, Mo, Pb, Th, Ti, and scattered Y are present in stream-sediment samples. Estimates of the probabilities of undiscovered quartz-adularia and quartz-alunite gold-silver veins are shown in **table 6-10**.

Using these estimates, computer simulation shows a 70 percent probability of no undiscovered quartz-adularia veins deposits, a 22.5 percent probability of one deposit, a 4.5 percent probability of 2 deposits, and a 3 percent probability of 3 or more deposits. The mean number of deposits expected is 0.3969. Expected means of metal tonnages are 7.9 tonnes Au, 540 tonnes Ag, 180 tonnes Cu, 0.61 tonnes Pb, and 6.8 tonnes Zn contained in 1.3 million tonnes of mineralized material. In addition, a 6.67 percent probability of no quartz-alunite veins and a 93.33 percent probability of one or more such deposits was computed. An expected mean of 0.9322 quartz-alunite vein deposits containing 35 tonnes Au, 200 tonnes Ag, and 34,000 tonnes Cu, in 4.2 million tonnes of mineralized material. Adding the results of simulations for epithermal vein deposits shows expected mean totals for the area as 43 tonnes Au, 740 tonnes Ag, 34,000 tonnes Cu, 0.61 tonnes Pb, and 6.8 tonnes Zn contained in 5.6 million tonnes of mineralized material. Comparing these tonnages to the other areas favorable for epithermal vein deposits shows that this area has the highest expected mean tonnage of gold and the fourth highest total mean tonnage of mineralized material.

Animas Mountains Favorable Area

Animas Mountains favorable area is one of 11 areas favorable for the occurrence of epithermal manganese deposits, based on the presence of known deposits of this type, and the locations of Muir, Rincon, the southwestern part of Gillespie, and the southern tip of Lordsburg mining districts. The area includes Muir caldera and parts of Juniper, Animas Peak, Tullous, Cowboy Rim, and San Luis calderas to the south. The shape of the area follows the trend of known deposits along the western side of the Animas Mountains, becoming bulbous on the northern end in order to include Muir caldera and areas to the north.

This area was assessed to have moderate potential for undiscovered epithermal manganese deposits. The assessment for this area ranges from a 50 percent probability of one undiscovered epithermal manganese deposit to a one percent probability of 4 or more such deposits . Results of the computer simulation using the estimates show a 30 percent probability of no undiscovered epithermal manganese deposits, a 40 percent probability of one deposit, a 22.5 percent probability of 2 deposits, a 4.5 percent probability of 3 deposits, and a 3 percent probability of 4 or more deposits. The mean number of deposits expected is 1.1224. Expected means of metal tonnages are 48,000 tonnes Mn and 520 tonnes Fe contained in 150,000 tonnes of mineralized material (the fourth highest tonnage of the areas favorable for epithermal manganese deposits in the study area).

Antelope Wells-Dog Mountains Favorable Area

Antelope Wells-Dog Mountains favorable area is defined as being favorable for the occurrence of epithermal manganese deposits by the presence of a known occurrence of this type in the Antelope Wells-Dog Mountain mining district. The district lies in a gravity low. Geomagnetic data are low throughout the region. Low gravity and magnetic results may be indicative of hydrothermal alteration and possible epithermal mineral deposits. Geochemical spot anomalies of As, Bi, Cd, Cu, Zn, Mn, Mo, and Nb, more widespread anomalies of K, La, Th, and Y, and combined moderate concentrations of aeroradiometric K, U, and Th, may also be indicators of epithermal mineral deposits.

The assessment team thought the area had moderate potential for undiscovered epithermal manganese deposits. Estimates show a 10 percent probability of 2 deposits and a one percent probability of 3 deposits. Results of computer simulation using the estimates show a 60 percent probability of no undiscovered epithermal manganese deposits, a 20 percent probability of 2 deposits, and a 17 percent probability of 3 or more deposits. The mean number of deposits expected is 0.6119. Expected mean tonnages are 24,000 tonnes Mn and 240 tonnes Fe contained in 79,000 tonnes of mineralized material. The expected mean tonnage of manganese is the second lowest of the 11 favorable areas estimated for that deposit type.

Burro Mountains Favorable Area

This area is favorable for the occurrence of undiscovered epithermal manganese deposits (not for quartz adularia veins, quartz-alunite gold-silver veins, or sediment-hosted gold deposits). Santa Rita trend traverses the area from northeast to southwest. The area includes Black Hawk, Bound Ranch, Burro Mountains, Gold Hill, Malone, and White Signal mining districts. It is underlain chiefly by Precambrian granites in the Burro Mountains and lies on the northwest-trending magnetic high of the Burro Uplift. Low gravity anomalies are typical. Geochemical anomalies of Ag, Be, Co, Cu, K, La, Mo, Nb, Pb, Ti, U, Y, and Zn are present in

parts of the area. Rare-earth pegmatites exist in the southern part of the favorable area and, in Bound Ranch district, fluorite veins are abundant.

Results of computer simulation using the estimates show 30 percent probabilities of either zero or one undiscovered epithermal manganese deposit, a 20 percent probability of 2 such deposits, and a 20 percent probability of 3 or more such deposits. The mean number of deposits expected is 1.3007. Expected mean metal tonnages are 52,000 tonnes Mn and 670 tonnes Fe contained in 170,000 tonnes of mineralized material.

Carrizalillo Favorable Area

Carrizalillo favorable area is one of five areas favorable for the occurrence of both epithermal manganese and quartz-adularia gold-silver veins. It includes the Carrizalillo mining district, which is located where gravity and magnetic lows coincide. Aeroradioactivity measurements for K, U, and Th show that K is moderate and U and Th are average. Geochemical stream-sediment samples yielded anomalies of As, Ba, Cd, Co, Cr, La, Mn, Pb, Sb, Th, Y, and Zn.

Estimates for the number of undiscovered epithermal manganese and quartz-adularia gold-silver deposits are shown in **table 6-10**. Results of the computer simulation show a 56.67 percent probability of no undiscovered quartz-adularia gold-silver deposits, a 13.33 percent probability of 1 such deposit, a 13.33 percent probability of 2 such deposits, and a 16.67 percent probability of 3 or more such deposits. The mean number of deposits expected is 0.9154. Expected mean amounts of metal in these deposits are 19 tonnes Au, 1,100 tonnes Ag, 340 tonnes Cu, 1.4 tonnes Pb, and 14 tonnes Zn, contained in 3.1 million tonnes of mineralized material. There is a 60 percent probability of no undiscovered epithermal manganese deposits, a 20 percent probability of one such deposit, a 12.5 percent probability of 2 deposits, a 4.5 percent probability of 3 deposits, and a 3 percent probability of 4 or more deposits. The mean number of deposits expected is 0.6821. These deposits have expected mean tonnages of 28,000 tonnes Mn and 290 tonnes Fe contained in 88,000 tonnes of mineralized material.

Cora Miller Favorable Area

Cora Miller favorable area extends from Cora Miller mining district northward almost to Cliff along the Gila River. The area was delineated by the Cora Miller mining district, which contains known epithermal mineralization, and known mineral occurrences. A Mn geochemical anomaly provides additional criteria for delineating the shape of the area. The district lies along the eastern edge of Schoolhouse Mountain caldera, which may have been a source for the heat, fluids, and fractures necessary for formation of vein deposits. Semi-circular chains of magnetic highs indicate caldera borders, ring-fracture intrusions, or contrasts between volcanic rocks that either

form the walls of the caldera or are deposited as moat deposits. Linear magnetic lows over mid-Tertiary volcanic rocks and a nearby magnetic high indicate altered zones along faults that may host mineralization. Geochemical anomalies of La, Mn, Mo, Nb, Sn, and Y and spot anomalies of Be, Co, Cr, Cu, K, and U are found in stream-sediment samples and may be indicative of epithermal mineralization along the caldera wall.

Estimates of the number of undiscovered quartz-adularia gold-silver deposits are shown in **table 6-10**. Results of the computer simulation show there is a 70 percent probability of no undiscovered deposits of this type, a 27 percent probability of one such deposit, and a 3 percent probability of two or more such deposits. The mean number of deposits expected is 0.3317. Expected mean metal tonnages are 6.0 tonnes Au, 420 tonnes Ag, 140 tonnes Cu, 0.54 tonnes Pb, and 6.1 tonnes Zn contained in 1.1 million tonnes of mineralized material.

Doña Ana Mountains Favorable Area

Doña Ana Mountains favorable area for the occurrence of quartz-adularia gold-silver vein deposits includes the Doña Ana Mountains and Doña Ana mining district. It is a small part of the Rincon-Doña Ana favorable area, which is favorable for the occurrence of epithermal manganese deposits. The probability of undiscovered epithermal manganese deposits in the Rincon-Doña Ana favorable area is discussed in a separate section.

Doña Ana Mountains favorable area was delineated as favorable for the occurrence of epithermal quartz-adularia gold-silver vein deposits by the presence of gravity and magnetic highs that coincide with the location of the mining district. The gravity high wraps around the northwest side of the caldera and is probably the result of intrusion of igneous rocks into the caldera. Geochemical anomalies of Be, spot As, and Ti occur in the area, and Co, La, and U anomalies occur at the north end of the mining district. The area has a distinct aeroradiometric feature indicating elevated concentrations of K, U, and Th.

Estimates of the number of undiscovered the quartz-adularia gold-silver deposits are shown in **table 6-10**. Results of the computer simulations using the estimates found that there is a 60 percent probability of no undiscovered deposits of this type, a 20 percent probability of one such deposit, a 17 percent probability of 2 deposits, and a 3 percent probability of 3 or more such deposits. The mean number of deposits expected is 0.5935. Expected mean amounts of metal in these deposits are 11 tonnes Au, 760 tonnes Ag, 230 tonnes Cu, 0.89 tonnes Pb, and 9.8 tonnes Zn contained in 2.1 million tonnes of mineralized material.

Florida Mountains Favorable Area

Florida Mountains favorable area is one of 5 areas favorable for the occurrence of both epithermal manganese deposits and quartz-adularia gold-silver veins. The area includes the eastern part of Florida Mountains and all of Little Florida Mountains mining districts, where numerous epithermal manganese deposits and other types of mineral deposits are present. Florida Mountains district occurs on gravity and magnetic highs. Little Florida Mountains district is on a partial gravity high, but there is no corresponding magnetic high. Aeroradiometric K, U, and Th are undistinguished in both districts. Geochemical anomalies of As, Ba, Be, Cd, Co, Cu, K, La, Nb, Pb, Sn, Th, Ti, Y, and Zn occur in stream-sediment samples in both districts. Hot-springs fluorite and manganese deposits occur on the northeast side of the Little Florida Mountains district, mineralizing pediment gravels.

Estimates of the number of undiscovered epithermal manganese and quartz-adularia gold-silver deposits are shown in **table 6-10**. Results of the computer simulations using the estimates show a 6.67 percent probability of no undiscovered epithermal manganese deposits, a 63.33 percent probability of one deposit, a 22.5 percent probability of 2 deposits, a 4.5 percent probability of 3 deposits, and a 3 percent probability of 4 deposits or more. The expected mean number of epithermal manganese deposits is 1.3321. Expected mean metal tonnages in these deposits are 50,000 tonnes Mn and 720 tonnes Fe contained in 160,000 tonnes of mineralized material.

Results of the computer simulation show a 70 percent probability of no undiscovered quartz-adularia gold-silver deposits, a 22.5 percent probability of one deposit, and a 7.5 percent probability of 2 deposits or more. The expected mean number of undiscovered quartz-adularia gold-silver deposits is 0.3729. Expected means of metal tonnages are 7.6 tonnes Au, 470 tonnes Ag, 150 tonnes Cu, 0.56 tonnes Pb, and 6.6 tonnes Zn, contained in 1.3 million tonnes of mineralized material. Total expected mean tonnages for both deposit types are 7.6 tonnes Au, 470 tonnes Ag, 150 tonnes Cu, 0.56 tonnes Pb, 50,000 tonnes Mn, 720 tonnes Fe and 6.6 tonnes Zn contained in 1.4 million tonnes of mineralized material. The expected mean tonnage of manganese is the second highest for areas favorable for epithermal manganese deposits.

Fluorite Ridge Favorable Area

Fluorite Ridge favorable area mimics the outline of Fluorite Ridge mining district. On the southwest, known epithermal manganese deposits are present. Manganese-bearing placers occur in the vicinity as residual concentrations resulting from erosion of the of the epithermal manganese deposits. The area is underlain by a gravity high; there is a magnetic high northwest of the district.

Aeroradiometric K, U, and Th are undistinguished. Geochemical anomalies of As, Be, Cd, Cr, Cu, Mn, Pb, Ti, and Zn are present.

Team estimates for the number of undiscovered epithermal manganese deposits are shown in **table 6-10**. Results of the computer simulation using the estimates show a 30 percent probability of no undiscovered epithermal manganese deposits, a 61.25 percent probability of one deposit, a 2.5 percent probability of 2 deposits, and a 6.25 percent probability of 3 or more deposits. The mean number of deposits expected is 0.8284. Expected means of metal tonnages in these deposits are 33,000 tonnes Mn and 510 tonnes Fe contained in 100,000 tonnes of mineralized material.

Fremont Favorable Area

Fremont favorable area is located at the Hidalgo County-Luna County-Mexico border, corresponding closely to the boundary of Fremont mining district. The area is favorable for the occurrence of epithermal quartz-adularia gold-silver veins and carbonate-hosted deposits. It lies on the edge of the Apache Hills caldera and is part of a northwest trend that parallels the Texas lineament. Spot geochemical anomalies of As, Bi, Cd, Pb, and Sb are identified in stream-sediment samples. The area is located on regional gravity and magnetic highs, and there is speculation about a possible porphyry system.

The assessment team estimated a 10 percent probability of 2 undiscovered quartz-adularia gold-silver deposits and a 5 percent probability of 3 such deposits. Given these estimates, the computer determined a 60 percent probability that no quartz-adularia gold-silver deposits occur, a 20 percent probability of one deposit, a 12.5 percent probability of 2 deposits, and a 7.5 percent probability of 3 deposits. There is an expected mean of 0.6747 deposits. Expected mean metal tonnages in quartz-adularia veins are 14 tonnes Au, 810 tonnes Ag, 300 tonnes Cu, 0.92 tonnes Pb, and 12 tonnes Zn contained in 2.3 million tonnes of mineralized material.

Gila Fluorspar Favorable Area

Gila Fluorspar favorable area is favorable for the occurrence of both quartz-adularia and quartz-alunite gold-silver veins, and includes Gila Fluorspar mining district. This area was chosen also as being favorable for the occurrence of undiscovered porphyry copper mineralization. The area lies south of the mid-Tertiary Bursum caldera; fractures that parallel the ring-fracture zone are within the favorable area. The area is underlain by a magnetic high, and lies on a gravity gradient. Stream-sediment geochemical anomalies of Ag, Ba, Co, Cu, Mn, Mo, Nb, Pb, Y, and Zn are present. Zones of intense argillic hydrothermal alteration and epithermal fluorite occurrences are

present (Ratté and others, 1979). Aeroradiometric U is high, and a Th low is offset from the U high.

Using the estimates that there is a 10 percent probability of 2 undiscovered quartz-adularia gold-silver deposits and a 5 probability of 3 deposits, the computer simulation found a 60 percent probability of no undiscovered quartz-adularia veins deposits, a 20 percent probability of one such deposit, a 12.5 percent probability of 2 deposits, and a 7.5 percent probability of 3 or more deposits. The mean number of these deposits expected is 0.6517. Expected mean metal tonnages are 12 tonnes Au, 840 tonnes Ag, 220 tonnes Cu, 1.0 tonnes Pb, and 11 tonnes Zn contained in 2.1 million tonnes of mineralized material.

In addition, the team estimated a 10 percent probability of one undiscovered quartz-alunite gold-silver deposit. With that estimate, the computer simulation determined a 70 percent probability of no quartz-alunite vein deposits and a 30 percent probability of one or more deposits. The expected mean number of deposits is 0.2865. Expected mean metal tonnages in quartz alunite gold-silver deposits are 9.3 tonnes Au, 53 tonnes Ag, and 6,000 tonnes Cu contained in 1.3 million tonnes of mineralized material. Adding the results of the simulations for epithermal vein deposits, the expected mean totals for the area are 21 tonnes Au, 890 tonnes Ag, 6,200 tonnes Cu, 0.61 tonnes Pb, and 11 tonnes Zn contained in 3.4 million tonnes of mineralized material.

Gillespie Favorable Area

Gillespie favorable area includes the northeastern Gillespie mining district, where known epithermal mineral deposits exist at Gillespie and Red Hill mines. The area lies at the junction of four calderas (Animas Peak, Cowboy Rim, Juniper, and Tullous) and lies on low-amplitude gravity and magnetic highs. Carbonate rock is exposed; part of the area is favorable for carbonate-hosted and epithermal vein deposits. Aeroradiometric K, U, and Th are low. Geochemical anomalies of Ag, As, Be, K, La, Mn, Nb, Th, Ti, U, and Y occur in stream-sediment samples. Gold is anomalous at Athena fluorspar mine.

Estimates show a 10 percent probability of 3 undiscovered quartz-adularia gold-silver deposits. Given the estimates, the computer simulation program determined a 56.67 percent probability that no deposits of this type occur, 13.33 percent probabilities of 1-2 deposits, respectively, and a 16.67 percent probability of 3 or more deposits. The expected mean number of deposits is 0.8720. Expected means of metal tonnages in quartz-adularia veins is 19 tonnes Au, 1,100 tonnes Ag, 360 tonnes Cu, 1.3 tonnes Pb, and 13 tonnes Zn contained in 3.2 million tonnes of mineralized material.

Kimball Favorable Area

Kimball favorable area for the occurrence of both epithermal manganese and quartz-adularia gold-silver veins includes Kimball mining district and overlies an elongate gravity high beneath the mining district. A magnetic low underlying the area may be indicative of hydrothermal alteration; a magnetic high lies to the east. Aeroradiometric K is relatively higher than U. Geochemical anomalies of Ag, Cu, La, Mn, Pb, and Sn occur in stream-sediment samples.

Team estimates show a 10 percent probability of 3 undiscovered epithermal manganese deposits, a 10 percent probability of one undiscovered quartz-adularia gold-silver deposit, and a one percent probability of 3 deposits. For quartz-adularia deposits, results of the computer simulation show a 56.67 percent probability of no undiscovered deposits, 13.33 percent probability of 1 such deposits, 13.33 percent probability of 2 such deposits, and a 16.67 percent probability of 3 or more such deposits. The mean number of deposits expected is 0.9154. Expected mean metal tonnages are 18 tonnes Au, 1,100 tonnes Ag, 320 tonnes Cu, 1.6 tonnes Pb, and 16 tonnes Zn contained in 3.0 million tonnes of mineralized material. These numbers compare favorably to those of the Carrizalillo area, where similar estimates were made. For epithermal manganese deposits, results of the computer simulation show a 70 percent probability of no undiscovered deposits, a 22.5 percent probability of one deposit, a 4.5 percent probability of 2 deposits, and a 3 percent probability of 3 or more deposits. The mean number of deposits expected is 0.4119. Expected means of metal tonnages are 17,000 tonnes Mn and 270 tonnes Fe contained in 53,000 tonnes of mineralized material.

Old Hadley Favorable Area

Old Hadley favorable area is favorable for the occurrence of both quartz-adularia and quartz-alunite gold-silver veins. The area contains the Old Hadley mining district--the district and area outlines are identical. Rocks in the district consist of mostly Tertiary andesites and other volcanic rocks. There are no recognized geophysical gravity or magnetic anomalies, but the area overlies the edge of a magnetic high. Aeroradiometric anomalies of K and U surround the district. Geochemical anomalies of As, Bi, Cd, Mo, Pb, and Zn and spot anomalies of Ag, Sb, and Th are found in stream-sediment samples.

Estimates of undiscovered quartz-adularia gold-silver deposits and quartz-alunite gold-silver deposits are shown in **table 6-10**. Computer simulation using the estimates determined that there is a 70 percent probability of no undiscovered quartz-adularia veins deposits, a 22.5 percent probability of one deposit, a 4.5 percent probability of 2 deposits, and a 3 percent probability of 3 or more deposits. The mean number of deposits expected is 0.4137. Expected mean metal tonnages are 8.9 tonnes Au, 560 tonnes Ag, 140 tonnes Cu, 0.87 tonnes Pb, and 7.3

tonnes Zn contained in 1.4 million tonnes of mineralized material. The computer determined that there is a 92.5 percent probability of no quartz-alunite vein deposits and a 7.5 percent probability of one or more deposits. The expected mean number of deposits is 0.0752. Expected meanmetal tonnages are 2.7 tonnes Au, 13 tonnes Ag, and 2,000 tonnes Cu, contained in 330,000 tonnes of mineralized material. Adding the results of the simulations for epithermal deposits indicates the expected mean totals for the area are 12 tonnes Au, 580 tonnes Ag, 2,200 tonnes Cu, 0.87 tonnes Pb, and 7.3 tonnes Zn, contained in 1.8 million tonnes of mineralized material. Comparing these tonnages to Alum Mountain and Gila Fluorspar favorable areas shows that this area has the lowest expected mean tonnage of gold in the study area in quartz-adularia and quartz-alunite vein deposits.

Rincon-Doña Ana Favorable Area

Rincon-Doña Ana favorable area is delineated by occurrence of a string of epithermal manganese deposits along the Rio Grande River in the northern part of Doña Ana County, and by geochemical and geophysical evidence. The area includes Rincon, Tonuco Mountain, Doña Ana Mountains, and Tortugas Mountain mining districts, where small epithermal and carbonate-hosted mineral deposits occur. Epithermal manganese deposits are common in the Doña Ana Mountains, and commonly occurring travertine is evidence for hydrothermal activity; in the Radium Springs area, hot springs attest to ongoing geothermal activity. In Rincon district, elevated concentrations of Ba, Cu, Co, Mn, Pb, Ti, and Zn are recognized in stream-sediment samples, and similar samples in the Doña Ana Mountains district are anomalous in Co, La, Nb, Pb, Th, Ti, and Zn. In that district, gravity and magnetic highs are related to Doña Ana caldera and subsequent intrusions. Elevated aeroradiometric K, U, and Th are indicative of rhyolitic rocks in the vicinity of the caldera. Stream-sediment samples in Tortugas Mountain district are locally anomalous in Co, La, Mn, Mo, Nb, Pb, Th, and U.

Using the team estimates, computer simulation determined a 30 percent probability of no such deposits, a 30 percent probability of one deposit, a 20 percent probability of 2 deposits, and a 20 percent probability of 3 or more deposits. The mean number of deposits expected is 1.3133. Expected mean metal tonnages in epithermal manganese deposits is 51,000 tonnes Mn and 610 tonnes Fe contained in 160,000 tonnes of mineralized material.

San Francisco-Steeple Rock Favorable Area

San Francisco-Steeple Rock favorable area occupies the northwestern corner of the study area, extending from the Grant County-Catron County-Greenlee County AZ juncture southward to near Virden and eastward to near Lordsburg Mesa. The area is bounded on the east by Mangas trench, and includes San Francisco and Steeple Rock mining districts. Steeple Rock district has had significant past production, including Carlisle mine, and many known mineral occurrences; it

is the site of continued mining activity. Hells Hole porphyry system, consisting of Tertiary volcanic andesite and rhyolite, lies between San Francisco and Steeple Rock districts. Acid-sulfate alteration is pervasive locally. San Francisco mining district overlies a magnetic high and gravity low. Ag, Cu, Pb, and Zn are anomalous in stream-sediment samples. Aeroradiometric K, U, and Th are undistinguished. Steeple Rock mining district overlies a NW-trending gravity gradient and magnetic low. The magnetic low may be indicative of commonly occurring acid-sulfate alteration. Stream-sediment geochemical anomalies of Ag, Ba, spot Be, Co, Cu, La, Mn, Mo, Pb, spot Sn, Th, Ti to the north, Y, and Zn are recognized in the district. An aeroradiometric K high is present in the northern periphery of the district. Estimates indicate favorability for the occurrence of quartz-adularia gold-silver veins in the San Francisco-Steeple Rock area. A smaller area, called Steeple Rock favorable area and centered around the Steeple Rock mining district, is the only area favorable for the occurrence of both epithermal manganese and quartz-alunite gold-silver veins.

Estimates of undiscovered quartz-aduaria and quartz-alunite gold-silver vein deposits and epithermal manganese deposits are shown in **table 6-10**. Results of the computer simulation using those estimates found that there is a 20 percent probability that no quartz-adularia gold-silver deposits occur in the area, a 20 percent probability of one deposit, a 30 percent probability of 2 deposits, a 22.5 percent probability of 3 deposits, a 4.5 percent probability of 4 deposits, and a 3 percent probability of 5 or more deposits. The expected mean number of deposits is 1.7986. Expected mean metal tonnages in quartz-adularia veins are 36 tonnes Au, 2,300 tonnes Ag, 660 tonnes Cu, 2.9 tonnes Pb, and 26 tonnes Zn contained in 6.1 million tonnes of mineralized material.

There is a 70 percent probability that no undiscovered quartz-alunite gold-silver deposits are present, a 22.5 percent probability of one deposit, a 4.5 percent probability of 2 deposits, and a 3 percent probability of 3 deposits. The expected mean number of deposits is 0.4045. Expected total mean metal tonnages in quartz-alunite veins are 14 tonnes Au, 75 tonnes Ag, and 11,000 tonnes Cu, contained in 1.8 million tonnes of mineralized material. Computer simulation show a 30 percent probability of no undiscovered epithermal manganese deposits, a 40 percent probability of one deposit, a 27 percent probability of 2 deposits, and a 3 percent probability of 3 or more deposits. The expected mean number of deposits is 1.0278. Expected mean metal tonnages are 42,000 tonnes Mn and 570 tonnes Fe contained in 130,000 tonnes of mineralized material. Total expected mean metal tonnages in the San Francisco-Steeple Rock favorable area are 50 tonnes Au, 2,400 tonnes Ag, 11,000 tonnes Cu, 2.9 tonnes Pb, 26 tonnes Zn, 42,000 tonnes Mn, and 570 tonnes Fe, contained in 8.1 million tonnes of mineralized material. Seventy-two percent of the

gold and approximately 97 percent of the silver are in quartz-adularia gold-silver veins. Quartz-alunite veins contain 95 percent of the copper.

Sierra Rica Favorable Area

Sierra Rica favorable area is favorable for the occurrence of sediment-hosted gold deposits, owing to the volcanic epithermal vein and carbonate-hosted deposits of Apache No. 2 and Fremont districts which are within its boundary, and also to the presence of a sediment-hosted gold deposit at the Amanacer mine across the border in northern Sonora, Mexico. The area is included in Apache favorable area for porphyry deposits. Besides the presence of mining districts, there are geochemical anomalies of As, possibly Be, Bi, Co, Cu, K, La, Mo, Pb, Sb, Th, U, Y, and Zn. Gravity and magnetic highs underlie much of the area. A distinctive aeroradiometric K, U, and Th anomaly indicative of the presence of carbonate rocks further suggests the potential for undiscovered mineral deposits. A small part of Apache Hills caldera is included in the district, and associated volcanic activity and subsequent caldera collapse may have provided a necessary source of heat, fluids, and faults and fractures for formation of epithermal vein mineralization.

Using team estimates, results of the computer simulation determined a 70 percent probability of no undiscovered sediment-hosted gold deposits and a 30 percent probability of one or more such a deposits. The mean number of deposits is 0.2977. Expected means of metal tonnages are 18 tonnes Au and 0.16 tonnes Ag contained in 9.0 million tonnes of mineralized material.

Silvertip Favorable Area

Silvertip favorable area was delineated as favorable for the occurrence of undiscovered epithermal quartz-adularia gold-silver deposits, owing to known epithermal mineralization in the district in Arizona, and because the area lies within Geronimo Trail caldera. Interpretation of gravity and magnetic anomalies shows the presence of the caldera wall and intrusive rocks. Geochemical anomalies in stream-sediment samples may be indicative of mineralization. The team estimated a 50 percent probability of one epithermal quartz-adularia gold-silver vein deposit , a 10 percent probability of 2 deposits, and a 5 percent probability of 3 or more deposits. Computer simulation based on the team estimates determined a 30 percent probability of no undiscovered quartz-adularia gold-silver deposits, a 40 percent probability of one deposit, a 22.5 percent probability of 2 deposits, and a 7.5 percent of 3 or more deposits. The mean number of deposits expected is 1.0714. Expected means of tonnages are 460 tonnes Cu, 20 tonnes Au, 1,300 tonnes Ag, 17 tonnes Zn, and 1.3 tonnes Pb contained in 3.6 million tonnes of mineralized material.

Telegraph Favorable Area

Telegraph favorable area is favorable for the occurrence of both epithermal manganese and quartz-adularia gold-silver veins. It contains Telegraph mining district and the southern rim of Schoolhouse Mountain caldera (Luedke, 1993). The favorable area is about three times larger than the mining district. Stream-sediment geochemical anomalies of Ag, Ba to the north, Cr, Cu, K, Nb, Pb, Sn, Th, Ti, and Zn are recognized; fluorspar is common. Much mineralization is probably related to the intrusion of Tyrone stock in the Burro Mountains. Aeroradiometric anomalies having high Th, and low U and K are larger than the mining district. The favorable area lies on a gravity high and a transverse magnetic ridge that crosses a SW-trending magnetic low.

Results of the computer simulation using estimates for the number of undiscovered epithermal manganese and quartz-adularia gold-silver deposits show a 30 percent probability of no undiscovered quartz-adularia gold-silver deposits, a 40 percent probability of one deposit, a 22.5 percent probability of 2 deposits, and a 7.5 percent probability of 3 or more deposits. The mean number of quartz-adularia gold-silver deposits expected is 1.0566. Expected means of metal tonnages are 21 tonnes Au, 1,300 tonnes Ag, 420 tonnes Cu, 2.0 tonnes Pb, and 15 tonnes Zn, contained in 3.6 million tonnes of mineralized material. There is also a 60 percent probability of no undiscovered epithermal manganese deposits, a 20 percent probability of one deposit, a 12.5 percent probability of 2 deposits, and a 7.5 percent probability of 3 or more deposits. The mean number of epithermal manganese deposits expected is 0.6599. Expected mean metal tonnages are 29,000 tonnes Mn, and 300 tonnes Fe contained in 91,000 tonnes mineralized material.

Victorio Favorable Area

Victorio favorable area is one of three areas (along with Sierra Rica and Winkler Anticline) favorable for the occurrence of sediment-hosted gold deposits. This part of the northern Cordilleran Thrust Belt south of the Burro Uplift was delineated by Victorio mining district, occurrence of a suspected porphyry molybdenum, low fluorine deposit in the district, and carbonaceous calcareous rock. The boundary outlines an underlying gravity high that defines a shelf of carbonate or volcanic rock buried approximately 0.8 km from the surface. Seismic data confirms that high velocity rocks (4 km/sec) are within one km of the surface. A distinctive aeroradiometric K, U, and Th anomaly, indicative of carbonate rock, is identified. Geochemical anomalies of Be, spot Bi, Co, spot La, Mn, Pb, and Zn are found in stream-sediment samples from the area, and gold is found in jasperoid.

Estimates show a 5 percent probability of one undiscovered sediment-hosted gold deposit. Computer simulation using this estimate determined a 92.5 percent probability of no undiscovered sediment-hosted gold deposits and a 7.5 percent probability of one or more deposits. The mean

number of deposits expected is 0.0770. Expected means of metal tonnages are 5.6 tonnes Au and 0.054 tonnes Ag contained in 2.2 million tonnes of mineralized material.

Wilcox Favorable Area

Wilcox favorable area borders the southern rim of Bursum caldera where it enters Grant County. The area includes the southern part of Wilcox mining district that extends into the county along the edge of the Mangas trench. The mining district coincides with a gravity low and a magnetic high. A faint gravity high is aligned with the district, and may indicate a fault zone. Stream-sediment geochemical anomalies of Ag, Be, Cu, Cr, K, spot Mn, Th, Ti, U, Y, and Zn are present, along with epithermal vein mineral occurrences.

Wilcox favorable area is favorable for the occurrence of both epithermal manganese and quartz-adularia gold-silver veins. Estimates of the numbers of undiscovered deposits of these types are shown in **table 6-10**. Computer simulation for both undiscovered epithermal deposits and undiscovered quartz-adularia gold-silver vein deposits shows a 60 percent probability of no deposits, a 20 percent probability of one deposit, a 12.5 percent probability of 2 deposits, and a 7.5 percent probability of 3 or more deposits for each deposit type. The mean numbers of epithermal manganese and quartz-adularia gold-silver vein deposits are 0.6453 and 0.6615, respectively. Undiscovered epithermal manganese deposits are expected to contain mean metal tonnages of 28,000 tonnes Mn and 370 tonnes Fe in 86,000 tonnes of mineralized material. Undiscovered gold-silver vein deposits are expected to contain mean metal tonnages of 15 tonnes Au, 810 tonnes Ag, 220 tonnes Cu, 1.4 tonnes Pb, and 8.6 tonnes Zn in 2.4 million tonnes of mineralized material.

Winkler Anticline Favorable Area

Winkler Anticline favorable area is favorable for the occurrence of undiscovered sediment-hosted gold deposits, based on the reported presence of silty carbonate rock and jasperoid, locally containing detectable gold. As delineated, the area does not include Gillespie mining district but, because of its close proximity to that district, the area would support a geothermal system if the Tertiary igneous rocks in the favorable area are the same age as those in the mining district. Estimates of the probabilities of undiscovered sediment-hosted gold deposit show a one percent probability of one or more deposits. Computer simulation determined a 97 percent probability of no undiscovered sediment-hosted Au deposits and a 3 percent probability of one or more such a deposits. The mean number of deposits is 0.03002. Expected mean metal tonnages are 1.4 tonnes Au and 0.020 tonnes Ag contained in 640,000 tonnes of mineralized material.

Undiscovered Resources in Epithermal Deposits

Results of the computer simulations using the estimates provided by the assessment team shows that the expected mean number of undiscovered epithermal deposits is 10.72 quartz-adularia gold-silver deposits, 9.94 epithermal manganese deposits, 1.70 quartz-alunite gold-silver deposits, and 0.40 sediment-hosted gold deposits in the study area. The expected mean metal tonnages are 300 tonnes Au, 14,000 tonnes Ag, 57,000 tonnes Cu, 17 tonnes Pb, 170 Zn, 400,000 tonnes Mn, and 5,100 tonnes Fe contained in 58 million tonnes of mineralized material. These tonnages account for approximately 57 percent of the Au, 37 percent of the Ag, and 28 percent of the Mn expected to occur in the study area. Negligible percentages of base metals are also present in these deposit types.

Epithermal manganese deposits are expected to contain a mean metal tonnage of 400,000 tonnes Mn and 5,100 tonnes Fe in 1.3 million tonnes of mineralized material. In contrast, replacement manganese deposits contain expected mean tonnages of 1.0 million tonnes Mn, 1,900 tonnes Fe, and 20 tonnes Cu in 3.5 million tonnes of mineralized material. Epithermal manganese deposits are expected to provide only 40 percent of the manganese as that provided by replacement manganese deposits.

Of the gold-bearing epithermal deposit types estimated, quartz-adularia deposits are expected to be the most numerous and the most important source of precious metals, containing an expected mean of approximately 220 tonnes Au and 13,000 tonnes Ag. Quartz-alunite deposits are next in importance as a source of precious metals, with approximately 62 tonnes Au and 340 tonnes Ag. Sediment-hosted gold deposits are expected to be least numerous and contain approximately 25 tonnes Au and 0.24 tonnes Ag.

Estimates of the expected metal tonnages in epithermal deposits at various probability levels are shown in **figure 6-8A-D**. At the 50 percent probability level (or confidence level), there is a 50-50 chance that undiscovered epithermal manganese deposits in the study area will contain at least 310,000 tonnes Mn, in 1.0 million tonnes of mineralized material. As the level of confidence decreases (the percent probability lowers), the tonnages of metals and mineralized material increase. At the 10 percent confidence level, there is one chance in 10 that the undiscovered epithermal manganese deposits will contain at least 870,000 tonnes Mn, and 24,000 tonnes Fe in 2.6 million tonnes of material. Tonnages for gold-bearing epithermal deposit types rise just as dramatically. At the 50 percent confidence level, the estimated undiscovered quartz-adularia gold silver vein deposits contain at least 150 tonnes Au, 5,700 tonnes Ag, and 760 tonnes Cu in 24 million tonnes of mineralized material. At the 10 percent confidence level, the tonnages rise to at least 460 tonnes Au, 33,000 tonnes Ag, 11,000 tonnes Cu, 79 tonnes Pb, and 800 tonnes Zn in 88

million tonnes of material. If we had 100 areas similar to the study area, 10 of them could be expected to contain those tonnages of metals and material.

At the 50 percent confidence level, undiscovered quartz-alunite gold-silver vein deposits are estimated to contain at least 35 tonnes Au and 110 tonnes Ag in 5.5 million tonnes of mineralized material. At the 10 percent confidence level, the tonnages rise to and 160 tonnes Au and 1,000 tonnes Ag in 19 million tonnes of mineralized material. At the 50 percent confidence level, there are no sediment-hosted gold deposits. At the 10 percent confidence level, sediment-hosted gold deposits contain at least 34 tonnes Au in 18 million tonnes of mineralized material.

VOLCANOGENIC MASSIVE SULFIDE DEPOSITS

Volcanogenic massive sulfide deposits form on the seafloor as a result of submarine volcanic activity. The deposit group consists of Besshi, Cyprus, or Kuroko type deposits, for which there are deposit models. Volcanogenic massive sulfide is the deposit name used herein, rather than the individual deposit model names Besshi, Cyprus, or Kuroko, because the assessment team felt that their presence is speculative, and the team did not know enough about the depositional history and composition of the rocks in the tracts to distinguish which of the three types were most likely to occur.

In New Mexico, volcanogenic massive sulfide deposits form in Precambrian rocks that range in age from about 1,760 m.y. to 1,650 m.y. old. They are usually composed of metavolcanic rock, pillow lava, or metamorphosed pillow lava, especially in greenstone terranes. However, no known volcanogenic massive-sulfide deposits occur in the study area. Two locations within the eastern part of the study area were identified by Robertson and others (1986) as being of the proper rock type (felsic-dominated volcanic rocks) and the proper age (1,660 to 1,650 m.y.) for the occurrence of massive sulfide deposits.

Favorable areas for volcanogenic massive sulfide deposits (**plate 6**) include Precambrian rocks that may represent submarine volcanogenic activity in an ancient arc or rift system (Robertson and others, 1986). Three areas favorable for the occurrence of massive sulfide deposits were delineated by the assessment team. They include areas of known mafic Precambrian rocks about 1,600 Ma in age. These rocks are similar to those in Grandview and Sulfur Canyons in Sierra County to the north. Favorable areas are described below.

Using geological, geophysical, and geochemical information in this report and information on the mineral occurrences in the study area and adjacent to it, the assessment team estimated the numbers of undiscovered volcanogenic massive sulfide deposits at the 90, 50, 10, 5, 1, 0.5, and 0.1, percent confidence levels (**table 6-12**).

For each of the three areas, the assessment team estimated that there is a 0.1 percent probability for the occurrence of one volcanogenic massive sulfide deposit. The Kuroko massive sulfide deposit model, which was modified to include only deposits of known Precambrian age, was used in the computer simulation. This model is appropriate, since it best fits the depositional environment of the rocks in the study area (**table 6-13**) shows the results of the computer simulation. The variability in tonnages among the favorable areas, having started with the same estimates of the probability of undiscovered deposits, shows the variability possible in the computer simulation.

Areas Favorable for the Occurrence of Volcanogenic Massive Sulfide Deposits

Burro Mountains Favorable Area

Burro Mountains favorable area is located in the northern Big Burro Mountains, extending from Telegraph and Black Hawk mining districts to exposures along the eastern edge of Fleming mining district. The area is on a magnetic high. It includes exposed Precambrian schist and amphibolite and the expanse between them where similar rocks may be buried.

Results of the computer simulation using the team estimate shows a 99.7 percent probability of no volcanogenic massive sulfide deposits and a 0.3 percent probability of one deposit . Expected mean tonnages are 1,100 tonnes Cu, 0.0025 tonnes Au, 4,800 tonnes Zn, 5.1 tonnes Ag, and 190 tonnes Pb contained in 34,000 tonnes of mineralized material.

Gold Hill Favorable Area

Gold Hill favorable area occurs in and adjacent to Gold Hill mining district and includes Precambrian schist and amphibolite. In some places, Quaternary sediments overlie Precambrian rocks. The area coincides with a magnetic high that wraps around the southern Burro Mountains, and may indicate hydrothermal magnetite deposition in inferred carbonate rock on the mountain flanks. Geochemical anomalies of Cr, Mn, Mo, Pb, and Zn are present in stream-sediment samples.

Computer simulation using the team estimate of a 0.1 percent probability of one undiscovered deposit shows a 99.7 percent probability of no volcanogenic massive sulfide deposits and a 0.3 percent probability of one deposit. Expected mean tonnages are 300 tonnes Cu, 0.060 tonnes Au, 520 tonnes Zn, 2.1 tonnes Ag, and 27 tonnes Pb contained in 46,000 tonnes of mineralized material.

San Andres Favorable Area

San Andres favorable area extends southward from the northern boundary of Doña Ana County less than half the length of the San Andres Mountains. Delineation of the area boundary is based on bedrock exposures and a gravity high, and includes all outcrops and buried Precambrian

rocks within one km of the surface. Within in this favorable area, volcanogenic rocks about 1,600 m.y. old crop out. The rocks are described by Robertson and others (1986) as favorable for the occurrence of volcanogenic massive sulfide deposits.

Computer simulation using the team estimates shows a 99.7 percent probability of no volcanogenic massive sulfide deposits and a 0.3 percent probability of one deposit. Expected mean metal tonnages are 21 tonnes Cu, 0.00098 tonnes Au, 60 tonnes Zn, 0.033 tonnes Ag, and 4.4 tonnes Pb contained in 1,700 tonnes of mineralized material.

Undiscovered Resources in Volcanogenic Massive Sulfide Deposits

Given the very low probabilities that the assessment team estimated for the occurrence of these deposits in each of the three favorable areas, the total tonnages of undiscovered metals are likewise small. There is a 99.75 percent probability that none of the 3 favorable areas will contain a deposit of this type, and a 0.25 percent probability that one of the areas will contain a deposit. The expected mean number of deposits is 0.0074. Expected total mean metal tonnages for the 3 areas are 1,400 tonnes Cu, 0.063 tonnes Au, 5,400 tonnes Zn, 7.3 tonnes Ag, and 230 tonnes Pb contained in 82,000 tonnes of mineralized material.

Figure 6-9 shows the expected tonnages of metals and material in volcanogenic massive sulfide deposits at probabilities of less than one percent. At the 0.75 percent probability level these deposits will contain at least 800 tonnes Cu in 100,000 tonnes of mineralized material. That is, if there were 100 areas like the study area less than one of them could be expected to contain 800 tonnes of Cu and 100,000 tonnes of mineralized material.

OTHER DEPOSIT TYPES

Rhyolite-hosted tin and gold placers are grouped here because they form by processes other than those that form porphyry, metallic vein, epithermal, carbonate-hosted, and volcanogenic massive sulfide deposits. Rhyolite-hosted tin deposits form under igneous conditions, but not through the interaction of hydrothermal or epithermal fluids. Gold placers form under conditions unrelated to igneous rocks.

Rhyolite-Hosted Tin Deposits

Rhyolite-hosted tin deposits are generally hosted in metaluminous to slightly peraluminous rhyolite or latite, forming as tin-rich vapor is redeposited as cassiterite on the outer rind of a cooling lava. Five areas were chosen as being favorable for the occurrence of undiscovered rhyolite-hosted tin deposits. No deposits of this type have been identified, but north of the area in the Black Range in Catron and Sierra Counties, several deposits of this type have been discovered, and small amounts of tin have been mined from lode deposits and placers. Likewise, in the Franklin Mountains of Texas, a small amount of tin was produced from a deposit of this type

(Harbour, 1972). The deposit model is based on published reserve figures, and may understate the final mineral production for the deposits. Locations of favorable areas are shown in **plate 7** and are described below. Estimates of undiscovered rhyolite-hosted tin deposits are shown in **table 6-14**, and expected mean tonnages of tin in favorable areas are shown in **table 6-15**.

Areas Favorable for the Occurrence of Rhyolite-Hosted Tin Deposits

Animas favorable area

Animas favorable area extends the length of the Animas Mountains, from the New Mexico-Mexico border northward to about the latitude of the New Mexico-Texas border to the east. Gravity and magnetic data are generally high and non-diagnostic. However, magnetic and gravity highs define the northern border of Cowboy Rim caldera. The area is favorable for the occurrence of rhyolite-hosted tin deposits based on the occurrence of volcanic centers, calderas, and abundant rhyolite host rocks in which these deposits may form. Scattered tin geochemical anomalies are also indications of potential mineralization. The Douglas pre-assessment (Hammarstrom and others, 1987) selected this area as being permissive for epithermal deposits, including a porphyry tin system.

The assessment team estimated a 0.1 percent probability of one or more rhyolite-hosted tin deposits. Results of computer simulation using estimates of undiscovered rhyolite-hosted tin deposits show a 99.7 percent probability of no such undiscovered deposits and a 0.3 percent probability of one deposit. The expected mean number of undiscovered deposits is 0.0030. Expected mean metal tonnage is 0.023 tonnes Sn in 3.5 tonnes of mineralized material.

Alamo-Hueco favorable area

Alamo-Hueco favorable area is a semi-circular area located at the lower, southeastern corner of the heel in New Mexico, at the New Mexico-Mexico border. The area includes the Alamo-Hueco and Dog Mountains and Alamo Hueco-Dog Mountains mining district. The area is favorable for the occurrence of rhyolite-hosted tin deposits, since abundant rhyolite exposures and scattered tin anomalies in geochemical stream-sediment samples are present. There is a non-diagnostic gravity high, and magnetic data are variable. A small part of the area was selected in the Douglas pre-assessment (Hammarstrom and others, 1987) as permissive for epithermal deposits, including a porphyry tin system.

Estimates show a 0.1 percent probability of one or more rhyolite-hosted tin deposit. Results of the computer simulation using estimates of rhyolite-hosted tin deposits shows a 99.7 percent probability of no such undiscovered deposits and a 0.3 percent probability of one deposit. The expected mean number of deposits is 0.0030. Expected mean metal tonnage is 0.028 tonnes Sn in 6.0 tonnes of mineralized material.

Black Range-Northern Grant County favorable area

Black Range-Northern Grant County favorable area is the largest of the areas favorable for the occurrence of undiscovered rhyolite-hosted tin deposits in the study area. It stretches from the Grant County-Catron County border southward to Mangas Valley. The boundary of the area is defined arbitrarily based on geologic and geochemical information. A gravity low marking the Mogollon volcanic field and a complex pattern of magnetic highs over Emory Caldera help to define the caldera shape. Thick accumulations of volcanic andesites and rhyolites typify the area. The rhyolites are similar to, and are locally continuous with, the tin-bearing rhyolites in the Taylor Creek tin district, Sierra County (Ratté and others, 1979). No known tin veins exist, but tin geochemical stream-sediment anomalies are widespread. As much as 200 parts per million (ppm) Sn occurs in stream-sediment samples (Ericksen and others, 1970), and stream-sediment samples having 15 or more ppm Sn show a distribution pattern around tin-bearing rhyolite outcrops. Cassiterite is found in stream-sediment samples (Ericksen and others, 1970), and small tin placers may occur in drainages adjacent to rhyolite-hosted tin deposits or may form by erosion. No deposit model exists for tin placers formed near rhyolite-hosted tin deposits.

Estimates of undiscovered rhyolite-hosted tin deposits show a 50 percent probability of one deposit and a one percent probability of 2 or more deposits. Results of the computer simulation using estimates of undiscovered rhyolite-hosted tin deposits show a 30 percent probability of no such undiscovered deposits, a 67 percent probability of one deposit, and a 3 percent probability of 2 or more deposits. The expected mean number of deposits is 0.7251. Expected mean metal tonnage is 9.0 tonnes Sn contained in 1,400 tonnes of mineralized material.

Mule Creek-Steeple Rock favorable area

Mule Creek-Steeple Rock favorable area extends northward from the Gila River in the Virden area to the Grant County-Catron County line, and westward to the Arizona-New Mexico border. The boundary is defined using geological, geophysical, and geochemical information. The area is in the gravity low associated with the Mogollon volcanic field. Rocks consists of thick accumulations of volcanic rock around a volcanic center. Tertiary intrusive rocks range in age from 35 m.y. to 18 m.y. (McLemore, 1993). Panned stream-sediment samples are anomalous in tin; tin placers may occur in drainages. Richter and others (1986) delineated part of the area permissive for the occurrence of a unique and unlikely porphyry tin system, wherein tin would occur as disseminated mineralization in the host rocks.

Estimates show a 5 percent probability of 2 rhyolite-hosted tin deposits. Results of the computer simulation using estimates for undiscovered rhyolite hosted tin deposits show a 91.25 percent probability of no such undiscovered deposits, a 2.5 percent probability of one deposit, and

a 6.25 percent probability of 2 or more deposits. The expected mean number of undiscovered deposits is 0.1484. The expected mean metal tonnage is 1.7 tonnes Sn contained in 280 tonnes of mineralized material.

Peloncillos favorable area

Peloncillos favorable area extends the length of the Peloncillo Mountains, from the New Mexico-Mexico border northward to near Steins; the basin on the west side of the range is excluded. Geochemical anomalies of Sn occur in stream-sediment samples from the area, as do anomalies for several other metals and elements. A broad gravity low and complex magnetic highs define the Peloncillo volcanic field. Parts of the Peloncillo Mountains are considered favorable for the occurrence of undiscovered porphyry, carbonate-hosted, metallic veins, and epithermal mineralization.

Using the geological, geophysical, and geochemical information reported herein and information on the mineral occurrences and adjacent areas, the assessment team estimates a 5 percent probability for one or more undiscovered deposits of rhyolite-hosted tin type. Computer simulation using this estimate yields a 92.5 percent probability of no such deposit and a 7.5 percent probability of one or more deposits. The expected mean number of deposits is 0.0714. The expected mean metal tonnage is 0.68 tonnes Sn contained in 130 tonnes of mineralized material.

Undiscovered Resources in Rhyolite-Hosted Tin Deposits

Using the estimates of the assessment team, the computer simulation determined a mean of 0.9509 rhyolite-hosted tin deposits in the 5 favorable areas. Four of the areas would contain no deposits; one area would be expected to contain one deposit. Total expected mean metal tonnage in the undiscovered deposit would be 11 tonnes Sn contained in 1,800 tonnes of mineralized material. Expected tonnages of tin at various probabilities are shown in **figure 6-10.**At the 70 percent confidence level, these deposits are expected to contain 0.35 tonnes Sn in 180 tonnes of mineralized material. At the 50 percent confidence level, an estimated 2.2 tonnes Sn will be present in 680 tonnes of material. At the 10 percent confidence level, these deposits can be expected to contain 29 tonnes Sn in 4,900 tonnes of mineralized material.

The relatively small tonnages of rhyolite-hosted tin deposits is reflected by the small mean metal tonnages in the deposit model. While this is a seemingly minute amount of tin, it compares favorably with the amounts produced in adjacent counties in New Mexico and with the 8 tonnes Sn from the Franklin Mountains of Texas (Harbour, 1972).

Gold Placer Deposits

Permissive tracts for gold placers (**plate 8**) include areas where ancient or modern drainage systems may have deposited alluvial gravels containing elemental gold and silver. Many

small gold placer deposits are present in the study area in dry stream beds draining areas having lode-gold deposits. In the past, many of the gold mining districts had a portion of their production in gold placers. However, development of known placers and exploration for undiscovered ones is not taking place currently, owing to the added cost of dry placer mining and the fact that alluvial gravels may be cemented by caliche, making the extraction of placer gold difficult.

Delineation of permissive tracts is based on the presence of known gold deposits and on the location of areas favorable for the occurrence of undiscovered gold-bearing deposits related to igneous rocks. The tracts include gravel deposits within 1.6 km (one mile) of the favorable areas. The 1.6-km limit was used, because the gold content of a drainage is diluted by the inflow of barren gravels as the distance from the gold source increases. Areas along the Gila, Rio Grande, and San Francisco Rivers are included in the tracts because they are known to contain small gold placers.

The tracts are permissive for gold placers where drainages emanate from areas permissive for epithermal gold deposits, gold-bearing porphyry deposits, skarn deposits, hydrothermal veins, replacement deposits, volcanogenic massive sulfide deposits, and other gold-bearing types. The source for the western part of the study area is mainly gold-bearing lode deposits that form in volcanic rocks; the eastern-most part of the study area is less reliant on epithermal deposits as sources of gold and more likely has porphyry deposits, skarn deposits, metallic vein deposits, and replacement deposits as sources.

The assessment of the Douglas 1˚ x 2˚ quadrangle (Hammarstrom and others, 1988) defined small tracts where modern and ancient gold placers may occur. Fossil placer tracts were delineated by the presence of basal Cambrian clastic units, including the Bolsa and Bliss Formations. Lower Cretaceous Glance Conglomerate in Gold Hill district is a known source of fossil placer gold. Modern placers were delineated by Pleistocene gravels in pediments rimming the Little Hatchet Mountains. Only a restricted part of the Gila and San Francisco River drainages have potential for gold placers in the Silver City 1˚ x 2˚ quadrangle (Richter and others, 1986). Richter and others (1986) estimated the gold resource in undiscovered gold placers to be less than about 10 tonnes Au.

According to Lasky (1936), a map of the placer ground in the Silver City region would be a map of the drainage area of pre-volcanic rocks, since the smallest intermittent channels in the region have yielded gold. The most productive placer grounds are north of San Jose Mountain and east of Central. Gold was derived from veins in the area. Experienced gold panners found that the gold content of the placer sands increased in proximity to a vein, and abruptly declined away from

it (Lasky, 1936). Gold dust with a fineness of 705 is the most common product of the placers, but nuggets as large as a small lima bean have been won locally.

In the study area, favorable areas were delineated near mining districts having reported placer gold production. Favorable areas are not described individually, as with other types of deposits; placers form in alluvial gravels by identical processes. Using the geological, geophysical, and geochemical information reported herein, and information on the mineral occurrences in the study area and adjacent to it, the assessment team estimated the numbers of undiscovered gold placer deposits at the 90, 50, 10, 5, 1, 0.5, and 0.1 percent confidence levels. The MARK-3 computer simulation program was used to calculate expected means of tonnages of gold and silver contained in those deposits.

Undiscovered Resources in Gold Placer Deposits

Results of computer simulation indicates that gold placers will be subordinate to other sources of gold in future mineral production. While the weekend recreational gold panner will continue to pan flakes and nuggets from ephemeral streams and arroyos, there is a low probability that undiscovered placers will support significant gold production. Using the team's estimates, a mean of 1.0426 gold placer deposits can be expected (**figure 6-11**). Of the eight favorable areas where estimates of undiscovered placer deposits were made, 7.1 of them will contain no such deposits. The remaining 0.9 areas will contain 1-2 deposits. Expected mean tonnages of precious metals are 2.3 tonnes Au and 0.077 tonnes Ag, contained in 14 million tonnes of gravel. Placers can be expected to contribute only about 0.4 percent of undiscovered gold resources and a negligible portion of silver resources. Computer simulation for gold placer deposits found that at the 90 percent probability level, no gold or silver could be expected. At the 50 percent probability level, gold placers are expected to contain 0.074 tonnes Au, but no Ag, in 430,000 tonnes of gravels; at the 10 percent probability level, 6.5 tonnes Au and 0.057 tonnes Ag are expected in 44 million tonnes of gravels, and at the 5 percent probability level, 12 tonnes Au, and 0.34 tonnes Ag, are expected in 89 million tonnes of gravels.

Sediment-Hosted Copper

Tracts permissible for sediment-hosted copper deposits are delineated by the presence of the Abo Formation, both on the surface and within one km of the surface (**plate 9**). Statewide, most copper mineralization in the Abo formation is in arkosic sandstone or locally in conglomerate. Host rocks are lenticular and discontinuous, and have a low probability for large undiscovered deposits. The Permian Abo Formation, exposed locally in northeastern Grant, northern Luna, and Doña Ana Counties, is a favorable host for stratiform sediment-hosted copper deposits elsewhere in New Mexico (Richter and others, 1986) and in particular, deposits in the Sierra Nacimiento,

Sandoval County (Woodward, 1987). In the Sierra Nacimiento area, permissive areas include both areas that are underlain by Abo redbeds and those underlain by transition zones, which are interpreted as tidal flat and shallow marine environments, where siliciclastic sedimentary rock is interbedded with carbonate rock (Mack and James, 1986). In the transition zone, the ratio of redbeds to carbonate rocks is less than 0.667 and greater than 0.25 (Kottlowski, 1965). Areas having less than a 20 percent clastic/carbonate ratio are permissible for the occurrence of sediment-hosted copper deposits, but the probability is low.

Exploration for copper in the Abo Formation in the Mimbres Resource Area should be directed a paleochannel locations where accumulations of carbonaceous detritus may provide a reducing environment favorable for mineralization. An area extending from central Luna County to northwestern Grant and northern Hidalgo Counties is not permissive for the occurrence of sediment-hosted copper deposits, since the Burro uplift and subsequent erosion have removed Abo rocks. Areas where rocks older than Permian are exposed likewise are not permissive for the occurrence of these deposits (**plate 9**).

In the Silver City quadrangle (Richter and others, 1986), despite a 100-yr mining history, sediment-hosted copper mineralization int he Abo Formation has never been reported, even though the area contains redbed formations, has abundant copper in veins and porphyries, and has identified gypsum resources. Some of the factors necessary for the formation of sediment-hosted copper deposits may be missing (see below). Locations of the favorable areas are shown in plate 9; the areas are described below. Estimates of undiscovered sediment-hosted copper deposits are listed in **table 6-14**. Expected mean tonnages of metals in favorable areas are shown in **table 6-15**.

Areas Favorable for the Occurrence of Sediment-hosted Copper Deposits

Mimbres favorable area

Mimbres favorable area was chosen as favorable for the occurrence of sediment-hosted copper deposits by the presence of redbed facies in Abo Formation rocks and the abundance of numerous copper-bearing deposits of other types. The area includes the northeastern part of Grant County and parts of northern Luna and Doña Ana Counties, including most of the area that Kottlowski (1965) outlined as underlain by rocks having a ratio of clastic rocks of the Abo Formation to carbonate rocks of the Hueco and Horquilla Formations of 20 percent or more. In a large part of the area, the Abo Formation makes up more than 89 percent of this clastic-carbonate sequence.

Using available information, the assessment team estimated a 10 percent chance for the occurrence of one deposit, and a one percent probability of 2 or more deposits. Results of the

computer simulation reveal that although the area has low potential for undiscovered sediment-hosted copper deposits, it contains relatively large tonnages of undiscovered metals. The expected mean number of deposits is 0.3289. Expected mean metal tonnages are 990 tonnes Ag, 900,000 tonnes Cu, and 13,000 tonnes Co, contained in 42 million tonnes of mineralized material.

Peloncillo favorable area

Peloncillo favorable area, including much of the area outlined by Kottlowski (1965), was delineated as favorable for the occurrence of sediment-hosted copper deposits by the presence of a greater-than-20-percent thickness of Abo Formation within a clastic-carbonate sequence, including an area where Abo Formation comprises more than 66 percent of the clastic-carbonate sequence.

Using the information presented herein, the assessment team estimated a 5 percent probability for the occurrence of one sediment-hosted copper deposit. The expected mean number of deposits is 0.0714. Expected means of metal tonnages are 220 tonnes Ag, 210,000 tonnes Cu, and 3,100 tonnes Co, contained in 9.1 million tonnes of mineralized material.

Undiscovered Resources in Sediment-Hosted Copper Deposits

Computer simulation using the estimates provided by the assessment team have determined that the expected mean number of undiscovered sediment-hosted copper deposits in the 2 favorable areas is 0.4003. There is an 81.63 percent likelihood of an area having no deposits, a 16.73 percent probability of one deposit, and a 1.64 percent probability of 2 deposits. Estimated undiscovered resources in sediment-hosted copper deposits at various probabilities are shown in **figure 6-12**.

At the 30 percent probability (or confidence) level, sediment-hosted copper deposits are expected to contain 44,000 tonnes Cu and no Ag or Co in 2.8 million tonnes of mineralized material. At the 10 percent confidence level (1 chance in 10), sediment-hosted copper deposits are expected to contain 0.12 tonnes Ag, and 2.0 million tonnes Cu in 110 million tonnes of mineralized material. At the 5 percent confidence level (1 chance in 20), these deposits are expected to contain 450 tonnes Ag, 5.7 million tonnes Cu, and 48,000 tonnes Co in 260 million tonnes of mineralized material. Expected means of metal tonnages in areas favorable for sediment-hosted copper deposits are estimated to be 1.1 million tonnes Cu, 1,200 tonnes Ag, and 16,000 tonnes Co contained in 52 million tonnes of mineralized material.

RESULTS OF COMPUTER SIMULATION

Totalling the tonnages of individual commodities that can be expected in the undiscovered mineral deposits in the study area at various probability levels (**figure 6-13**), the estimated undiscovered mineral wealth of the area is evident. At the 90 percent confidence level, for example, expected total mean metal tonnages are 200 tonnes Au, 11,000 tonnes Ag, 9.4 million

tonnes Cu, 9.1 million tonnes Fe, 450,000 tonnes Mn, 300,000 tonnes Mo, 470,000 tonnes Pb, 85 tonnes $WO_{3,}$ and 600,000 tonnes Zn; the metals are contained in an estimated total 2.5 billion tonnes of mineralized material. At the 90 percent confidence level (9 chances out of 10), the study area can be expected to contain these or greater tonnages. At the 50 percent confidence level (1 chance in 2), the area can be expected to contain 420 tonnes Au, 25,000 tonnes Ag, 28 million tonnes Cu, 82 million tonnes Fe, 1.2 million tonnes Mn, 820,000 tonnes Mo, 1.4 million tonnes Pb, 2.1 tonnes Sn, 21,000 tonnes WO_3, and 1.8 million tonnes Zn; the metals are contained in an estimated 6.5 billion tonnes of mineralized material. At the 10 percent confidence level (1 chance in 10 --good odds in the mining community), the area can be expected to contain 890 tonnes Au, 61,000 tonnes Ag, 0.0 tonnes Co, 78 million tonnes Cu, 630 million tonnes Fe, 2.7 million tonnes Mn, 1.9 million tonnes Mo, 4.0 million tonnes Pb, 29 tonnes Sn, 210,000 tonnes WO_3, and 4.9 million tonnes Zn; the metals are contained in 14 billion tonnes of mineralized material.

Estimates of the expected tonnages of undiscovered mineral commodities at various levels of probability may be compared to known quantities to give the estimates more meaning. For example, the resource estimates can be compared to reported past production figures to see what part of the total resource has been produced, or the resource estimates may be compared to the amounts of minerals the United States consumes annually to determine, on a national scale, what percentage of this consumption the undiscovered resources could fill. The following paragraphs make these and other comparisons.

GROSS IN-PLACE VALUES

Gross in-place values (GIPV) are a yardstick by which various commodities can be compared in identical units--dollars. GIPV of the undiscovered minerals are reported so that land management agencies can directly compare the value of the mineral resources to the in-place values of other resources such as wildlife, timber, water, and scenery. As Singer and Ovenshine (1979) point out, surface resources can be assessed quickly and accurately using proven methods. Mammals, birds, and other wildlife can be counted; water can be fished, tested, and have its volume calculated; timber can be appraised, and scenic resources can be photographed and described. Gross dollar values are placed on these resources to determine the best use of the land. Such is not the case for mineral resources, since they are mostly hidden in the subsurface and cannot be measured directly.

Prior to the development of quantitative mineral-resource assessment techniques, the USGS used qualitative methods that classified the likelihood for the occurrence of undiscovered mineral resources in an area as "high", "moderate", "low", "none", or "unknown". Land managers, however, had difficulty evaluating what these mineral potential values meant and how to

evaluate them fairly with GIPV of other resources.

Current techniques used by the USGS for subsurface undiscovered mineral-resource assessments allow the gross in-place values to be calculated so that the estimated values of the minerals can be compared with other values for land-use planning. In this assessment, GIPV have been calculated for undiscovered deposits for each commodity at selected probability levels.

Estimated GIPV do not imply, however, that the undiscovered mineral resources are necessarily economic to produce, any more than estimates of timber or scenic beauty values suggest economic viability. GIPV calculations are made irrespective of capital and operating costs of mine, mill, and infrastructure; these costs often preclude mining of many deposits. The mineral-deposit models on which the resource estimates are made contain grades and tonnages of deposits that may not contribute to the nation's resources in the foreseeable future. A determination of the economic viability of any mineral resource requires analysis of the costs of discovering the deposits, engineering feasibility studies of mining and concentrating ores, an economic evaluation of metal production, and market forecasts, in the same way that a forester must know the species, size, and condition of the trees, calculate transportation and fuel costs, and obtain timber-price forecasts, before he prudently can begin to harvest trees.

A closer look at the GIPV of expected mean tonnages of commodities in undiscovered mineral deposits (**table 6-16**) shows that copper has the highest value, with approximately $77 billion or 63 percent of the mean GIPV of all the metals in deposits within the Mimbres Resource Area. Porphyry copper-molybdenum deposits contain approximately $73 billion or 95 percent of the copper, with copper-skarn deposits a distant second. Metals with the second and third highest GIPV are iron and molybdenum, with approximately $15 billion or 12 percent and $13 billion or 10 percent of the total GIPV, respectively. All molybdenum is contained in porphyry deposits--98 percent in porphyry copper-molybdenum deposits, 2 percent in porphyry Mo, low fluorine deposits, and nearly all of the iron in iron-skarn deposits.

Gold, silver, zinc, and lead have greater than $1 billion each in total GIPV. Deposit types containing more than $1 billion dollars in both gold and silver are quartz-adularia gold-silver veins and porphyry copper-molybdenum deposits. Together these deposit types account for almost 65 percent of the total gold in undiscovered deposits. Polymetallic replacement deposit are the only type of deposit containing more than $1 billion in lead and zinc. This deposit type accounts for 70 percent of the lead and nearly 59 percent of the zinc in undiscovered deposits. Of those metals having GIPV of less than $1 billion, cobalt is the one having the highest GIPV. Manganese and tin are estimated to have the least GIPV. Mean GIPV of manganese is approximately $3.3 million; value of tin is approximately $220,000.

Total values of the contained commodities in each deposit type show porphyry copper-molybdenum deposits with a total of $89 billion in gold, silver, copper, lead, zinc, and molybdenum. This is by far the highest total GIPV for any deposit type. Iron skarn deposits contain $15 billion in expected mean totals of metals; quartz-adularia gold-silver veins contain $5.1 billion in expected mean totals of metals. Polymetallic replacement and zinc-lead skarn deposits have more than $1 billion GIPV of contained metals.

Total expected mean GIPV for a deposit type divided by the mean number of deposits expected gives the mean GIPV for deposits of that type. The 7.059 expected porphyry copper-molybdenum deposits, for example, have the highest mean GIPV, --almost $13 billion per deposit. Epithermal and replacement manganese deposits have the lowest GIPV, with $130,000 and $220,000, respectively. Iron skarn deposits contain approximately $3.1 billion --by far the highest GIPV for skarn deposits; gold-bearing skarn deposits contain $180 million each. Porphyry molybdenum, low fluorine deposits (relatively rare in the Mimbres Resource Area) contain approximately $2.7 billion; Au-Ag-Te veins (also relatively rare) contain approximately $1.4 billion each. Sediment-hosted gold deposits, with GIPV of $740 million each, have the highest GIPV of the epithermal deposit types. Volcanogenic massive-sulfide deposits contain approximately $1.5 billion in each deposit, but these deposits are estimated to be rare in the study area.

The GIPV per tonne of mineralized material in each deposit type can be calculated. Results show that high-volume, low-grade deposits types such as porphyry copper-molybdenum deposits have a GIPV of $12.64/t, and smaller deposits, such as polymetallic veins, that are worked using underground methods have a GIPV of nearly $310/t. Skarn deposits range from a high of $114/t for copper skarn deposits to $25/t for tungsten skarn deposits, and epithermal deposits range from $138 for quartz-adularia gold-silver veins to $1.03 for epithermal manganese veins, with sediment-hosted gold deposits having a GIPV of approximately $25/t. Polymetallic replacement deposits have a GIPV of approximately $158/t, Rio Grande Rift lead-zinc deposits have a GIPV of approximately $21/t, and replacement manganese deposits have a GIPV of less than $1/t. Gold placers have a GIPV of $1.96/t of gold-bearing gravels.

Table 6-17 shows ranking by GIPV of the favorable areas for the various groups of deposit types. The favorable area having the largest GIPV is the Peloncillo area, which was assessed for porphyry deposits, with an expected mean GIPV of $21 billion, or over 17 percent of the total. In fact, the areas with the 5 highest GIPV rankings were assessed for undiscovered porphyry deposits. The top 3 areas for undiscovered porphyry deposits contain expected mean GIPV totaling $53 billion, or over 43 percent of the total. The top 5 areas assessed for

undiscovered porphyry deposits are expected to contain $71 billion, or greater than 53 percent of the expected total GIPV in undiscovered deposits. Piños Altos-Santa Rita area, which was assessed for carbonate-hosted deposits, has the 6th highest GIPV, and was the highest ranked area not assessed for porphyry deposits. That area has a mean GIPV of $7.8 billion, or 6.4 percent of the total. San Francisco-Steeple Rock area has the highest ranking of those areas assessed for epithermal deposits, ranking 17th overall with a mean GIPV of approximately $850 million, or 0.6 percent of the total. Piños Altos area has highest ranking of those areas assessed for gold placers. That area ranks 57th overall, and contains a mean GIPV of $11 million, or 0.0088 percent of the total. Of the 94 favorable areas assessed for deposit types, from huge porphyries to small rhyolite-hosted deposits, the 15 highest ranked areas have expected mean GIPV of $1 billion or more. These areas account for $110 billion, or almost 90 percent of the total mean GIPV for the entire study area. In contrast, the 20 lowest-ranked areas (mainly those assessed for hydrothermal deposits, rhyolite-hosted tin deposits, epithermal deposits, and gold placers) have expected mean GIPV of less than $1 million each. These areas account for less than $5 million, or approximately 0.003 percent of the total. The highest ranked 47 areas contain over $121 billion, or 99.7 percent of the total. The 47 lowest ranked areas contain less than $370 million. The mean GIPV for the 94 areas assessed is almost $1.3 billion, and the median is approximately $45 million, demonstrating how the highest ranked areas can raise the mean GIPV for all areas.

Table 6-17 begs the question of which mountain ranges in the study area contain the greatest expected mean GIPV, after estimates of undiscovered resources in various deposit types within the range are combined. This information can be determined in only a general way, since, in some instances, the favorable areas were outlined into several tracts within a given mountain range, and in other instances, mountain ranges were combined into a single tract. **Table 6-18** lists undiscovered deposit types that may be included the aggregated areas (mostly mountain ranges and some districts) and the criteria used to delineate the favorable areas; **table 6-19** indicates the GIPV of the aggregated areas in the study area.

Aggregated favorable areas indicate that the Piños Altos-Santa Rita area has the greatest GIPV, at $24 billion. Peloncillo Mountains area contains the second greatest GIPV, with $22 billion in undiscovered resources. These two areas combined contain over 38 percent of the expected mean GIPV for the study area. San Andres-Organ Franklin Mountains area contains a GIPV of $19 billion (third largest in the study area), or 15.6 percent of the total. Each of these areas have been estimated to contain undiscovered porphyry copper-molybdenum deposits. Of the

24 aggregated areas, 5 have a GIPV of greater than $10 billion; an additional 6 areas have a GIPV of more than $1 billion, 9 have GIPV of more than $100 million, and 3 have a GIPV of less than $100 million.

ENDOWMENT/CONSUMPTION INDEX

The endowment/consumption (E/C) index is the number of years of U.S. consumption at an historic level (in this case the 1993 level), represented by the estimated mean tonnage of the commodities contained in undiscovered mineral deposits. **Table 6-20** lists the estimated 1993 tonnages, U.S. apparent consumption, and net import reliance of selected nonfuel mineral materials that occur in the study area. The index shows the importance of the area's undiscovered resources relative to national annual apparent consumption. Land managers may use the E/C index as a measure to help determine whether the estimated costs of exploring for and discovering a commodity in an area are warranted, given the expected gain in identified resources. This may be an important factor when land-use decisions concerning mineral exploration are being formulated or during a time of commodity shortages.

Table 6-20 shows that molybdenum, with an E/C index of greater than 61, has the highest index of the mineral commodities selected, and tin, with an index of 0.00024, has the lowest. That is, the mean amount of undiscovered molybdenum in the study area is enough to keep the U.S. supplied for more than 61 years at the 1993 rate of consumption, while the mean amount of undiscovered tin would meet this country's needs for tin for 0.00024 years or about 2 hours! Copper, with an E/C index of 15.48, and iron, with an E/C index of 11.49, are the commodities having the next highest E/C indices. These high indices are to be expected, given the optimistic estimates made for these large-volume deposits. Manganese and tungsten have E/C indices of 2.17 and 8.79, respectively. These figures suggest that if the country required emergency production of these commodities, as it has during past wartimes, there may be a contingency supply in undiscovered resources in the study area.

IMPORT RELIANCE

Another way to measure estimated mean volume of undiscovered mineral commodities in the study area is to compare that volume to the nation's net import reliance. **Figure 6-13** shows the U.S. 1993 net import reliance of those materials (U.S. Bureau of Mines, 1994). For several of these materials, such as manganese and tungsten, the U.S. has considerable apparent consumption and is strongly reliant on foreign sources to meet its needs. For gold and molybdenum, the U.S. is a net exporter, and for copper this country imports less than 10 percent of its apparent consumption. During times of national crisis in the past, mines have come on-stream to help meet National demands.

By evaluation of estimates of undiscovered resources of these materials, it can be determined that for molybdenum (U.S. is a gross exporter) or copper (U.S. imports 6 percent of its consumption), the large undiscovered resources in the study will help continue this trend. For metals such as manganese and tungsten, for which the U.S. is has a significant import reliance, the undiscovered resources in the study area could provide short-term supplies in times of crisis. For tin, however, the U.S. is highly reliant on foreign supplies and has only limited undiscovered resources in the study area.

UNDISCOVERED RESOURCES VS. PAST PRODUCTION AND ESTIMATED IDENTIFIED RESOURCES

Another way to look at the tonnages of undiscovered commodities is to compare them to both the amounts produced in the past and to the estimated identified resources in known deposits. These numbers indicate whether the undiscovered resources are less than or greater than the amounts already produced and discovered, and by how much. **Table 6-21** shows estimated resources (McLemore, this volume) and **table 6-22** shows past production figures for the study area and compares them to expected means of tonnages of selected base and precious metals in undiscovered mineral deposits.

The data for copper, for example, indicate that, since 1801,approximately 7.2 million tonnes Cu have been produced. In addition, more than 976,000 tonnes Cu have been reported as identified resources, and an expected mean of 38 million tonnes Cu remains in undiscovered mineral deposits. Adding these totals, total expected mean pre-production endowment is approximately 46 million tonnes of copper. Of this amount, past copper production accounts for 15.6 percent, identified resources about 2.1 percent, and 82.3 percent remains in undiscovered deposits. Ratios for other base and precious metals are shown on table 6-22.

CONCLUSIONS

Permissive tracts and 94 favorable areas have been delineated for the occurrence of mineral deposit types containing 11 mineral commodities. Geological, geochemical, and geophysical criteria for selecting the tracts and areas were used selectively in each area. Estimates of the probabilities of undiscovered mineral deposits in the permissive tracts and favorable areas have been entered into the MARK-3 computer simulation program, which found that the mean tonnages of the undiscovered mineral commodities are approximately 33,000 Ag, 530 tonnes Au, 17,000 tonnes Co, 38 million tonnes Cu, 210 million tonnes Fe, 1.4 million tonnes Mn, 990,000 tonnes Mo, 1.9 million tonnes Pb, 11 tonnes Sn, 75,000 tonnes WO_3 and 2.4 million tonnes Zn; these commodities are contained in 7.7 billion tonnes of mineralized material. There is a 10 percent probability that the area contains 890 tonnes Au, 61,000 tonnes Ag, 0.0 tonnes Co, 78 million

tonnes Cu, 630 million tonnes Fe, 2.7 million tonnes Mn, 1.9 million tonnes Mo, 4.0 million tonnes Pb, 29 tonnes Sn, 210,000 tonnes WO_3, and 4.9 million tonnes Zn; these tonnages are contained in 14 billion tonnes of mineralized material.

Porphyry-type deposits have the greatest tonnages in undiscovered resources. Porphyry copper-molybdenum deposits alone contain an estimated mean of 11,000 Ag, 120 tonnes Au, 36 million tonnes Cu, and 980,000 tonnes Mo, contained in 7.1 billion tonnes of mineralized material. Peloncillo, Piños Altos-Santa Rita, Organ, and Tyrone-White Signal areas have the largest mean undiscovered resources in porphyry copper deposits. Porphyry molybdenum, low fluorine deposits contain a mean of 16,000 tonnes Mo in 21 million tonnes of mineralized material.

Carbonate-hosted deposits have the next largest mean tonnages, having 5,700 Ag, 49 tonnes Au, 540,000 tonnes Cu, 210 million tonnes Fe, one million tonnes Mn, 1.8 million tonnes Pb, 75,000 tonnes WO_3, and 2.3 million tonnes Zn; these commodities are contained in 500 million tonnes of mineralized material. Piños Altos-Santa Rita, Victorio-Tres Hermanas, Little Hatchet-Sierra Rica, Lordsburg-Animas, and San Andres-Organ-Franklin areas contain the greatest gross in-place value (GIPV) of carbonate-hosted resources.

Epithermal deposits contain expected mean tonnages of 300 tonnes Au, 14,000 tonnes Ag, 57,000 tonnes Cu, 17 tonnes Pb, 170 tonnes Zn, 400,000 tonnes Mn, and 5,100 tonnes Fe, contained in 42 million tonnes of mineralized material. These deposits account for approximately 57 percent of the Au, 42 percent of the Ag, and 28 percent of the Mn expected to occur in the deposit types modeled in the study area. San Francisco-Steeple Rock, Alum Mountain, Telegraph, Silvertip, and Gila Fluorspar favorable areas have the greatest expected mean GIPV of undiscovered resources in epithermal mineral deposit types.

The remaining deposit groups have smaller expected mean tonnages of undiscovered resources. Metallic-vein deposits, for example, contain expected mean tonnages of 47 tonnes Au, 1,100 tonnes Ag, 1,300 tonnes Cu, 90,000 tonnes Pb, and 63,000 tonnes Zn, contained in 7.8 million tonnes of mineralized material. Au-Ag-Te veins contain approximately 44 tonnes of gold, or approximately 8.4 percent of the Au expected to occur in undiscovered deposits in the study area. Of the favorable areas having potential for undiscovered metallic vein deposits, Organ Mountains area has the greatest GIPV, owing to the potential for gold in Au-Ag-Te veins. Other favorable areas having hydrothermal deposits include Lordsburg, Burro Mountains, San Francisco-Caprock, and Piños Altos-Santa Rita areas.

Volcanogenic massive-sulfide deposits have a low probability of occurrence in the study area. Expected total mean metal tonnages for the 3 favorable areas are 1,400 tonnes Cu, 0.063 tonnes Au, 5,400 tonnes Zn, 7.3 tonnes Ag, and 230 tonnes Pb, contained in 82,000 tonnes of

mineralized material. Total expected mean tonnage in undiscovered rhyolite-hosted tin deposits is 11 tonnes Sn, contained in 1,800 tonnes of mineralized material. Black Range-Northern Grant County area is expected to contain the bulk of the tin in the study area. Undiscovered resources in gold placers have expected mean tonnages of 2.3 tonnes Au and 0.077 tonnes Ag, contained in 14 million tonnes of gravel. Of the areas favorable for undiscovered gold-placer deposits, Piños Altos-Santa Rita, Burro Mountains, White Signal, Gold Hill, and Sylvanite areas have the highest GIPV. Gold placers can be expected to contribute only approximately 0.44 percent of undiscovered gold resources and a negligible part of silver resources occurring in the area.

Results of MARK-3 computer simulations show that porphyry copper-molybdenum deposits contribute the largest portion (95 percent) of expected mean tonnages of copper, with copper skarn deposits (0.98 percent) having less significance. Most of the zinc (almost 59 percent) is contained in Rio Grande Rift lead-zinc deposits (much less --almost 37 percent-- is contained in zinc-lead skarn deposits); essentially all of the iron occurs in iron skarn deposits. Porphyry copper-molybdenum and porphyry molybdenum deposits account for all of the contained molybdenum. Undiscovered quartz adularia gold-silver veins (41 percent), porphyry copper-molybdenum (34 percent), and polymetallic replacement deposits (15 percent) can be expected to contain large amounts of silver. The most contained gold is present in quartz adularia gold-silver vein deposits (41 percent), porphyry copper-molybdenum deposits (24 percent), and quartz-alunite gold-silver vein deposits (12 percent). Polymetallic replacement deposits (70 percent), and zinc-lead skarn deposits(24 percent) contain the largest amount of lead. Tungsten skarn deposits were the only deposit type modeled for tungsten. Replacement manganese deposits are expected to contain approximately 2.5 times the amount of manganese of all epithermal manganese deposits.

The highest GIPV are contained in the porphyry deposits; porphyry copper-molybdenum deposits have the highest GIPV of any deposit type modeled. Carbonate-hosted deposits have the second-highest GIPV, but account for less than $^{1}/_{4}$ of the GIPV of the porphyry deposits. Epithermal deposits have the third highest GIPV, and the "other" deposit type group has the fourth highest GIPV. Metallic vein deposits and volcanogenic massive sulfide deposits have the lowest GIPV.

If the expected means of the mineral commodities estimated in this report reflect the undiscovered resources of the Mimbres Resource Area, then the area should continue to be a major producer of copper from porphyry-type deposits, and other metals such as molybdenum, lead, and zinc should continue to be produced in significant quantities. Gold and silver may be produced in greater abundance if more deposit types having gold as the primary product, such as

quartz-adularia gold-silver veins and Au-Ag-Te veins associated with alkaline rocks, are discovered.

INDUSTRIAL AND ENERGY MINERAL RESOURCES OF THE MIMBRES RESOURCE AREA

compiled by Susan Bartsch-Winkler

with sections on

NATURAL AGGREGATE

by William H. Langer, Gregory N. Green, James D. Bliss,

and Daniel H. Knepper, Jr.

ALUNITE AND ALUM (ALUMINUM); JAROSITE; MARBLE;

RICOLITE; SCORIA AND PUMICE

by Virginia T. McLemore

FLUORSPAR AND BARITE

by Alan R. Wallace and Virginia T. McLemore

IRON AND MANGANESE

by Daniel R. Hack

PERLITE

by James M. Barker and Ernest F. Scharkan

ZEOLITES IN TERTIARY VOLCANICLASTIC ROCKS

by Richard A. Sheppard

GEOTHERMAL POTENTIAL

by Wendell A. Duffield and Susan S. Priest

URANIUM OCCURRENCES

by Virginia T. McLemore

COAL RESOURCES

by J. David Sanchez

Commodities discussed in this section are categorized mainly as industrial commodities. Although overshadowed by the importance of porphyry copper and base-metal mining in the Mimbres Resource Area, they are highly varied and may be in sufficient quantity and quality to render them of future importance as mineral resources in this part of New Mexico (primarily an agrarian economy currently). Industrial minerals provide considerable potential for future development, as the area increases in population, or as world supplies of the products are depleted. Discussed in this section, and assessed qualitatively, are aggregate, alum, caliche, clay, dimension stone, travertine, calcite, talc, fluorspar and barite, gemstones and collectible minerals, guano,

gypsum, iron, jarosite, manganese, marble, perlite, ricolite, scoria and pumice, and zeolite. Discussions of energy resources include the potential for geothermal energy, coal resources, and oil and gas resources. Owing to the lack of deposit models, none of these commodities were assessed quantitatively.

MINERAL COMMODITIES

NATURAL AGGREGATE RESOURCES OF THE MIMBRES RESOURCE AREA, SOUTHWESTERN NEW MEXICO

by

William H. Langer, Gregory N. Green, James D. Bliss, and Daniel H. Knepper, Jr.

INTRODUCTION

To conduct an assessment of the natural aggregate of the Mimbres Resource Area (MRA), southern New Mexico, the USGS developed a method for utilizing a combination of third party geologic information and geologic experience. This regional assessment is based on subjective evaluations of 1:500,000–scale geologic maps and descriptive data to produce evaluations of the areal extent, quality, and volume of potential aggregate sources.

Natural aggregate is obtained from two major sources: (1) crushed stone and (2) sand and gravel. Crushed stone, as used in this report, is derived from bedrock that has been blasted, mined, and subsequently crushed and processed into aggregate. About 13,400 km^2 or 36 percent of the MRA is underlain with near–surface bedrock, although much of that rock is not suitable for use as high–quality aggregate. Sand and gravel deposits are unconsolidated sediments resulting from natural erosion of bedrock and surficial deposits and the subsequent transport, abrasion, and deposition of the more durable particles. About 23,400 km^2 or 64 percent of the area is underlain with unconsolidated materials[1].

The assessment of the regional availability of aggregate in the MRA covers an area of about 36,800 km^2. If the aggregate was only to be used as unspecified fill, every kind of rock and sediment in the MRA is potential aggregate. Austin and Kottlowski (1982) describe sand and gravel as "so widespread in New Mexico that much of a map showing geologic units containing potential deposits is covered." Similarly, the 1:5,000,000–scale maps in *Natural Aggregates of the*

[1]All areas were generated from digital maps which can be used to calculate areas to the nearest m^2. Those figures reported in this document were rounded to the nearest km^2 to avoid implying false accuracy.

Conterminous United States (Langer, 1988) show most of southwestern New Mexico as potential sources of sand and gravel or crushed stone. However, a variety of physical and chemical parameters restrict the use of material as aggregate in many common applications, thus eliminating large areas of bedrock and unconsolidated materials from consideration as potential aggregate resources. This report documents the limiting effects of quality factors on aggregate availability and focuses on the potential of higher quality natural aggregate in the MRA.

Most natural aggregate is used in the construction industry, especially in Portland cement concrete for residential and commercial buildings, bridges, and airports, and as portland cement concrete and bituminous mixes for highway construction. A large percentage is also used without a binder for road base, railroad ballast, and as road surfacing for low-volume roads. The four counties that comprise the MRA have a population of approximately 190,000. By including the population of the city of El Paso (which lies just south of the area across the New Mexico/Texas border), the market area for aggregate has a population of over 750,000. Considering that the per capita consumption of aggregate in New Mexico during 1994 was about 9 metric tons, the annual demand in the MRA can be projected to be about 6.75 million metric tons. In addition, the MRA is crossed by Interstate Highway 10, and the repair, restoration, and reconstruction of a typical interstate highway can consume as much as 11,275 metric tons of sand, gravel, and crushed stone per lane per kilometer. Given a design life span of 20 years, the maintenance of the 300–kilometer stretch of Interstate 10 that crosses the MRA could require a constant supply of as much as 675,000 metric tons of high-grade aggregate per year.

FACTORS IN REGIONAL AGGREGATE ASSESSMENT

It is important to understand the fundamental distinctions between regional assessments and site evaluations of aggregate. DuCharme (1967) pointed out that the scope of an aggregate survey should be commensurate with the anticipated commitment and results. For example, a study to determine the regional availability of aggregate for a preliminary assessment need not be as extensive as a survey to delineate a fifty–year source of supply for a crushed stone operation.

If aggregate is to be produced, certain conditions must be met:

(1) ***availability*** – geologic sources of aggregate must exist;

(2) ***quality*** – aggregate must meet physical and chemical requirements;

(3) ***quantity*** – volume must be sufficient for a profitable operation;

(3) ***minability*** – aggregate must physically be able to be mined;

(4) ***accessibility*** – the operation must be near transportation systems and markets;

(5) ***permitability*** – the site must qualify for all necessary permits; and

(6) ***economics*** – the operation must be profitable (Dreyer, 1976; Banino, 1994).

In conducting a regional assessment of aggregate, it is reasonable to evaluate only the first three conditions: *availability*, *quality*, and *quantity*. The last four conditions are only meaningful at a local or site scale. Furthermore, accessibility, permitability, and economics are all transient factors that can change with time.

Availability

Natural aggregate availability is described by the areal distribution of materials that are suitable for aggregate use. In a regional assessment, availability must be determined mainly from existing information, especially bedrock and surficial geologic maps and lithologic descriptions. For example, a preliminary map of potential crushed stone resources would consist of a map of all bedrock in a region and a preliminary map of sand and gravel resources would show the distribution of unconsolidated materials containing significant amounts of gravel. These preliminary resource maps would then be modified to reflect the physical and chemical properties of the bedrock and gravel deposits as discussed below. Quality considerations tend to greatly limit the area of materials containing potential aggregate sources.

Quality

Depending on the intended use, aggregate may or may not meet required quality specifications. In addition, specifications continually are modified, and aggregate that meets the specifications of today may not meet the specifications for tomorrow. The physical and chemical properties of crushed stone are a result of the geologic origin and mineralogy of the source rock, and the subsequent alteration or weathering. The physical and chemical properties of sand and gravel are a result of a combination of factors including the properties of the parent material, attrition during transport, sorting during deposition, and weathering after deposition.

When the evaluation process limits the selection of aggregates to only those areas that are likely to be free of physically weak or deleterious materials, large areas are removed from consideration. However, areas designated as lower quality may actually contain some quality aggregate or could be processed to meet higher quality requirements. Those areas may also contain aggregate that could be used for purposes that have less stringent quality requirements.

Lithology

A variety of rock types (or gravels derived from these rocks) make good sources of crushed stone. Hard dense limestones and dolomites (commonly are referred to in the aggregate industry as limestone) make up about 71 percent of U.S. crushed stone production. Coarse–grained, intrusive igneous rocks, particularly the light–colored ones (commonly are referred to in the aggregate industry as granite), comprise about 15 percent of U.S. crushed stone production. Fine–grained extrusive volcanic rocks, particularly the dark–colored ones (commonly are referred

to in the aggregate industry as trap), make up about 8 percent of U.S. crushed stone production. Hard dense metamorphic rocks make up approximately 4 percent of the total, and hard sandstones make up the remaining 3 percent of U.S. crushed stone production (Tepordei, 1993). All of these rock types, and gravels derived from these rocks, occur in the MRA.

Strength

Generally suitable aggregate is composed of essentially clean, unweathered, uncontaminated, uncoated particles of proper size, shape, strength, and durability, although the importance of specific physical properties depends primarily on how the aggregate will be used. Aggregates should have strength properties that resist mechanical breakdown resulting from the action of mixers, mechanical equipment, and (or) traffic. Fine–grained sedimentary rocks and some limestones (particularly those of Cretaceous age or younger) may be soft, absorptive, and friable, which result in poor aggregate quality. Of the metamorphic rocks, highly–foliated schist has little or no use as aggregate because of the inherent weakness caused by the parallel arrangement of the phyllosilicate minerals (micas). The physical properties (hardness, density) of most of the igneous rocks make them suitable for use as aggregate. However, some of the igneous rocks, as well as sedimentary and metamorphic rocks, have deleterious chemical properties that limit their usefulness as aggregate.

Silica Content

The chemical properties of aggregate commonly reflect those of the parent bedrock material, and may also be modified by subsequent weathering and secondary mineralization. Aggregate is considered an inert filler and should not change chemically once in place. However, some aggregates contain minerals that chemically react with or otherwise affect the Portland cement concrete or bituminous mixes. One of the most critical chemical processes, and generally most destructive reactions in Portland cement concrete, is the alkali–silica reaction (ASR), which is a reaction between specific types of silica in the aggregate and alkali in the cement pore solution (Stark, 1994)

Tridymite and cristobalite are minerals that are highly reactive when used with portland cement concrete. These minerals are minor constituents in near-surface intrusiverocks and volcanic rocks with glassy or devitrified groundmass, including rhyolite, latite, dacite, some andesite, and rocks of similar composition but with microcrystalline structure. Rocks such as obsidian, perlite, or pumice, and volcanic rocks where glasses occur as a portion of the groundmass may be reactive. Reactive opal and chalcedony occur in cracks and cavities of igneous rocks, in mineral veins, in hydrothermally altered rocks, in volcaniclastic rocks including tuffs and tuffaceous sedimentary rocks, and in some shales, sandstones, and carbonate rocks. They may also form as

coatings on gravels and sands. Mielenz (1994) has identified the Rio Grande and Gila River as two rivers in the MRA carrying alkali–reactive sand or gravel. Consequently, the above–mentioned rocks, and sand and gravel derived from them, should be very carefully evaluated if being considered for use as aggregate.

Contaminants

Some rocks, and gravels derived from those rocks, contain contaminants that limit their usefulness as aggregate. Gypsum, present in some sedimentary rocks, can disrupt the hardening of portland cement concrete. Metallic minerals such as lead or zinc oxides and pyrite can affect the setting of concrete or cause expansion problems. Certain zeolites (natrolite and heulandite) can increase the alkali content of cement paste; others (laumontite and leonhardite) can cause volume changes during wetting and drying (Dolar–Mantuani, 1983).

Quantity

Assessing the quantity of potential natural aggregate resources involves determining the three–dimensional configuration of each deposit (or rock unit) delimited on the potential resources maps for crushed stone and for sand and gravel. From the three–dimensional information, volumes of the deposits can be estimated. For regional assessments, quantity evaluations are usually hindered by the lack of deposit thickness and geometry information, as well as information about the vertical and lateral variability of the deposits. Gross evaluations of volume (high, medium, low) can sometimes be implied by the type of deposits involved; however, more meaningful assessments require more detailed information.

Thickness models for "typical" deposit types occurring in the region can be used to refine quantity estimates. These models attempt to characterize the thickness and variability of various deposit types based on detailed lithology–grain size–stratigraphy information obtained by field observations, drilling, trenching, and logging. Provided that the available detailed information is truly representative of most of the deposits, a quantitative estimate can be calculated. Nevertheless, regional volume estimates of usable aggregate resources tend to be highly inflated.

MIMBRES AGGREGATE ASSESSMENT

The assessment of natural aggregate potential in the MRA was conducted: (1) using published third–party information, (2) in a very short time, and (3) without the benefit of supporting field work. Consequently, an objective process to analyze third–party data was devised to assess the regional aggregate resource potential. Morey and others (1991) describe a procedure to analyze third–party data in the assessment of sand and gravel resources (at a scale of 1:50,000) of County Durham, United Kingdom. Their approach included limited field studies and numerous data points, but contained no provisions for descriptive comment on the quality of materials under

consideration. The approach designed for the MRA 1:500,000– scale assessment is similar to that for County Durham, but includes provisions for preliminary assessments of the quality of potential aggregate and has no provision for field investigations. A similar method was devised for the assessment of bedrock as a potential source for crushable stone. **Figure 7-1** and **figure 7-2** show the processes used to determine the natural aggregate potential of crushed stone and sand and gravel, respectively.

The process follows a three–step procedure:

(1) Preparation of aggregate resources maps.

(2) Definition of quality of crushed stone and sand and gravel

(3) Thickness estimates and volume calculations.

Because of the type of data used to assess the aggregate potential of the MRA and the lack of accompanying field studies, the results of the assessment reflect only broad trends of the aggregate availability in the MRA. Consequently, the resource potential maps prepared for the assessment are not intended to be used for site evaluations.

Crushed Stone Aggregate Resources Map

Figure 7-3 shows the availability and relative quality of potential sources of crushed stone in the MRA. The distribution of bedrock sources for crushable stone in the MRA was derived from a digital version of the *Geologic Map of the southwest quadrant of New Mexico* (Anderson and Jones, in press) that was digitally processed to show only areas of consolidated bedrock. The geologic map also contains descriptions of the lithologies of the all mapped bedrock units in the MRA. *A Field Guide to Natural Resource Assessmen*t (Langer and Knepper, 1995) relates rock lithologies to the performance of the rock if used as aggregate for portland cement concrete. Using those relationships, and comparing them to the lithologic descriptions of Anderson and Jones, the probability that a rock would perform as high quality natural aggregate was determined. Each rock unit was characterized as either *satisfactory* (green areas on figure 7-3) or *poor* (purple areas) potential sources of crushed stone; rock units described by Anderson and Jones as undifferentiated were identified as having *unknown* (blue areas) potential as crushed stone. As a result of this broad evaluation of the potential resource quality, only about 1,600 km^2 or 12 percent of the near–surface rock (4 percent of the total resource area) remains as potential sources of high–quality crushed–stone aggregate.

Sand and Gravel Aggregate Resources Map

By the process of elimination, the area of the *Geologic Map of the southwest quadrant of New Mexico* (Anderson and Jones, this volume) that does not contain bedrock, contains unconsolidated materials, including silts, clays, and sand and gravel deposits. The level of detail

of the mapped unconsolidated units on the map, however, was insufficient for determining which areas would most likely contain the sand and gravel.

The *Surficial Geology of Southwest New Mexico* (Hunt, 1978) identifies numerous surficial geologic units in the MRA according to the type of deposit and the grain size. This map was used to determine the areas of potential sources of sand and gravel in the MRA. From the descriptions of the surficial geologic units, it was determined that three map units most likely have sufficient gravel to be considered as potential sources of aggregate: (1) Alluvial fan deposits–gravel facies, (2) gravel terraces, and (3) floodplain and channel deposits along main streams. A digital map was prepared from the Hunt map by G.N. Green and P.S. Schruben (USGS) to show the distribution of these three units. These three units represent only about 8,400 km^2 or 35 percent of the total unconsolidated materials in the area; about 65 percent of the unconsolidated material in the area lacks significant amounts of gravel and has only very limited usefulness as aggregate.

Alluvial Fan Deposits–Gravel Facies

Many of the mountains in the MRA are ringed by alluvial fans or rock pediments which merge into an alluvial valley floor. Generally, gravels are most abundant and the overall deposit thickness is greatest in the proximal fan area (Blissenbach, 1954). Deposits in the mid–fan region consist of a mixture of grain sizes (including gravels) and are most distinguished by the interlayering of fluvial materials (crudely stratified) and mudflow (unstratified) deposits. The distal portion of the alluvial fans is characterized by finer grained, moderately to well–stratified materials and a relatively sharp gradation of the fan into the adjacent alluvial plains or alluvial deposits of streams flowing longitudinally down the valley. The far distal portion of the fan may be fringed by playa deposits (Fraser and Suttner, 1986). On short, steep (younger) fans, gravels show minimal weathering and may be weakly cemented with caliche. On the broad, gently– sloping (older) fans, gravels are more weathered and commonly are cemented by caliche (Hunt, 1978).

Gravel Terrace Deposits

In the eastern part of the MRA, the Rio Grande Valley spans the area from north to south. Extensive terraces flank the river and rise 45 m above the floodplain. River and stream gravels 30 to 45 m thick are interbedded with massive pockets of sand and silt (Lovelace and others, 1962). The terraces contain well–rounded gravels that have been reworked from river deposits as well as more angular fragments derived from local bedrock sources. Older gravels may be weathered and may contain caliche.

Floodplain and Channel Deposits

Hunt (1978) shows five types of alluvial deposits; one has been identified as having potential as a source of aggregate. These are floodplain and channel deposits along main streams. These areas are nearly flat but may contain terraces about 3 m high. The alluvial deposits commonly are sandy and silty stream deposits with layers of gravel and gravel terraces along valley sides.

Quality of Potential Sources of Sand and Gravel

The three surficial geologic units identified as probably containing significant amounts of gravel (alluvial fan–gravel facies; terrace; floodplain and channel) were rated to determine the relative availability of gravel clasts in each unit. The gravel facies of alluvial fans is the most likely of the three sand and gravel units to contain thick, unweathered gravel and was assigned an initial rating of *sufficient*. Terrace deposits are likely to contain lower percentages of gravel than fan deposits, and may also be weathered and cemented. Terrace deposits were assigned an initial rating of *marginal*. Alluvium is also likely to contain lower percentages of gravel than fan deposits and was also assigned an initial rating of *marginal*. All other unconsolidated materials were assigned a rating of *insufficient.*.

Next, bedrock source areas were identified for the gravel clasts in individual sand and gravel deposits and the probable quality of these clasts was determined from the resource map of crushable stone (**figure 7-3**). Each unit was rated for quality and assigned a value of *satisfactory, unknown or mixed lithologies*, or *poor* based on the lithologies of the rock units in the source area. Adequacy of gravel clasts was compared against source areas to determine the relative likelihood of finding adequate sources of quality aggregate within an area. Units were assigned a rating of *abundant*, *adequate*, or *limited* as shown in the figure below.

Figure 7-4 shows the relative availability and quality of potential sources of sand and gravel in the MRA. Abundant--Those areas where sand and gravel of suitable quality for use as aggregate is abundantly available are shown as green. Adequate--Blue areas are where sand and gravel of suitable quality for use as aggregate occurs in less abundant, but generally adequate, supplies; physical or chemical quality problems may occur, and some areas may be devoid of aggregate. Limited--Purple areas are where sand and gravel of suitable quality for use as aggregate occurs in very limited quantities; physical or chemical quality problems are likely to occur, and large areas may be devoid of aggregate. About 2,200 km^2 or 9 percent of the total area of unconsolidated materials remain where potential sources of high–quality aggregate are abundantly available; about 300 km^2 or 1 percent of the total area of unconsolidated materials has adequate supplies of aggregate; and about 5,900 km^2 or 25 percent of the total area of unconsolidated

materials has limited supplies of aggregate (**table 7-1**). In any area, land ownership, conflicting land use, regulations, and other societal and economic factors can restrict aggregate development.

Quantity of Sand and Gravel Resources

Volume estimates have only been prepared as part of this assessment for sand and gravel deposits. Because of the vertical and lateral variability of grain size distribution in individual sand and gravel deposits, estimations of the quantity of potential sand and gravel resources on a regional scale are extremely difficult. In addition, quantity estimates on a regional scale will probably have little application in the exploration for new resources. Aggregate exploration involves detailed site studies that include sampling, drilling and logging, trenching, ground–based resistivity mapping and other field–intensive studies to determine whether the quantity of aggregate present is sufficient for an economic operation. Nevertheless, regional quantity estimates, although probably inflated, illustrate that high quality aggregate is much less abundant than is usually anticipated.

Thickness Estimates

Average thicknesses for mapped units were derived by statistical analyses. Minimum thicknesses thought to be typical fan deposits (13 m) are calculated using data from 22 deposits in California reported by Cole and others (1987), Goldman (1964), Joseph and others (1987), and Stinson and others (1987). The data are given graphically in **figure 7-5**, where thickness is plotted on the horizontal axis and the cumulative proportion of deposits is plotted on the vertical axis. A curve is constructed using intercepts of the 90th, 50th, and 10th percentiles. The curve represents a lognormal (base 10) distribution that has a mean and a standard deviation that fits the data. The value at the 50th percentile is the single best number typifying the data.

The model of thickness of terraces (4.3 m) uses data found in Lovelace and others (1962) for 88 pits and prospects reported in terraces along the Rio Grande Valley both within and outside the Mimbres Resource Area (**figure 7-6**). The two thickness models used in estimating volumes of sand and gravel resources are additions to a number of other models already developed for sand and gravel deposits (Bliss and Page, 1994). Alluvial deposits have arbitrarily been assigned a thickness of 3 m based on an approximate working depth in areas with near–surface ground water.

Volume Estimates

Volume calculations at a regional scale have very limited application, and should only be used to either demonstrate the diminishing quantities of aggregate availability when considering quality parameters, or to make relative comparisons with other areas that have undergone similar assessments. Volumes were calculated by applying thickness values to specific deposit types, and totalling those volumes based on classifications of abundant, adequate, or limited (**table 7-2**). In the MRA there is approximately 28 billion m^3 of material that is likely to contain abundant

quantities of high–quality sand and gravel resources. Approximately 2.5 billion m^3 of unconsolidated material is likely to contain adequate quantities of sand and gravel resources of uncertain quality. Approximately 57 billion m^3 of unconsolidated material is likely to contain limited quantities of sand and gravel resources, and the quality of the gravel is likely to be poor.

Reliability of Results

Variability, or dispersion of values in sand and gravel deposit thickness data, is clearly visible in both thickness models discussed above. The variability of thickness values (**figure 7-5** and **figure 7-6**) is a combination of the natural variability of thickness among deposits plus the uncertainty in observing that thickness. Some, but not all, of the sources of uncertainty in data include: the use of depth as a proxy for thickness; the determination of thickness from natural surface exposures or pits which may not expose the entire thickness; the reported thickness is not typical of the deposit as a whole; and the thickness is reported as a minimum.

Other factors which affect variability include mixing different types of data and thickness cut-offs adopted for commercial extraction. Variability comes with mixing --measured thicknesses with estimated thicknesses, data from prospects or occurrences with data from worked pits, and data from surface exposures with data determined from drilling. Some thicknesses also include unsuitable material in sand and gravel deposits that are otherwise too thin to be mined. Such may be the case in thickness data for alluvial fans (**figure 7-5**) where 6 m appears to be either a minimum working thickness or other limiting economic consideration in California (the source of the data). Other types of minability issues that could affect the data are depth to water table, thickness of overburden, and stability of pit walls.

Terrace data are all from one source (Lovelace and others, 1962). This may bias the model in ways not recognized.

Uncertainty is unavoidable in modeling and can only be reduced, not eliminated. As uncertainties in the basic data are reduced, the variability in the model may not necessarily be reduced, or may be reduced only slightly. The variability contributed by uncertainty, although not necessarily large, might be relatively small compared to natural variability in the deposit thickness even if one could observe them under conditions of complete certainty.

The estimated volumes of sand and gravel do not bear any simple relationship to the amount that could be extracted in practice because the reliability of estimates relate to resources and not reserves. Equally important, the volume of sand and gravel estimated at the reconnaissance level commonly is significantly overestimated. The Alberta Geological Survey has operated a mineral aggregate assessment inventory for nearly 20 years and has determined a correlation between the scale of the assessment and the reliability of the data (Edwards, 1995). From their

experience only 10 to 30 percent of the volume of aggregate estimated at the reconnaissance level remains as potential aggregate when mapped at a scale of 1:10,000 (personal commun., Edwards, 1995). We believe those estimates approximate the reliability of the results of this assessment.

Estimates of Value

It is important to realize the fundamental distinction between resources and reserves. Minerals that are likely to be workable at some time in the future are classified as resources; the small part of the resources that are currently workable in the prevailing economy are reserves (Thurrell, 1981). In the industrial minerals industry, the identification of a market and its economic magnitude must be undertaken in order to determine the feasibility of resource development (Thompson, 1995). Dunn and others (1970) propose that the major factor that gives aggregate a measure of intrinsic value is the cost of transporting the aggregate to the market, and that a reserve closer to the market has an advantage over one farther from the market. They recommend utilizing a system that applies a *transportation advantage* to account for proximity to market. However, resources can move into and out of the reserve category with changes in demand, technology, and other socioeconomic factors. Therefore assessing the value of aggregate at the regional scale is not practical because there may be no current market at any price.

ALUNITE AND ALUM (ALUMINUM)

by

Virginia T. McLemore, NMBMMR

Alunite and alum are potential sources of aluminum. Alunite has been mined in several places in the world for its aluminum content (Hall, 1978; Hall and Bauer, 1983). Nearly all of the aluminum used in the United States comes from foreign sources, primarily from bauxite deposits (U.S. Bureau of Mines, 1992). During World War I, alunite was used as a source of potassium fertilizer. In the 1960s, the Soviet Union produced alunite for its aluminum content; potassium sulfate and sulfuric acid were recovered as by products (Hall and Bauer, 1983).

Alunite is one end member of a series of sulfates that occur in several geologic environments, all of which require base leaching of the host rock by acidic fluids. Minerals of the alunite group have the general composition $AB_3 (SO_4)_2 (OH)_6$ where A is typically K^+, Na^+, Pb^{++}, NH_4^+, or Ag^+ and B is typically Al^{+3} or Fe^{+3} (Brophy and others, 1962). Nine of the more common species are (Brophy and others, 1962; Altaner and others, 1988):

Alunite—$KAl_3(SO_4)_2(OH)_6$

Natroalunite - $NaAl_3(SO_4)_2(OH)_6$

Ammonioalunite - $NH_4Al_3(SO_4)_2(OH)_6$

Jarosite - $KFe_3(SO_4)_2(OH)_6$

Natrojarosite - $NaFe_3(SO_4)_2(OH)_6$

Ammoniojarosite - $NH_4Fe_3(SO_4)_2(OH)_6$

Argentojarosite - $AgFe_3(SO_4)_2(OH)_6$

Plumbojarosite - $PbFe_6(SO_4)_2(OH)_6$

Solid solution between the species is common. Alum is also one end member of a series of hydrous aluminum sulfates with the chemical formula $KAl(SO_4)_2 \cdot 12H_2O$.

Alunite and alum are found in six areas in the Mimbres Resource Area (**table 7-3**), where they are associated with volcanic-epithermal vein deposits and supergene alteration of porphyry copper deposits (McLemore, 1995). Alunite and alum typically occur with a variety of minerals including quartz, kaolinite, jarosite, pyrophyllite, and iron oxides. Pure alunite deposits are not found in New Mexico. However, local zones contain as much as 30 percent alunite in the Alum Mountain and Steeple Rock districts (Hall, 1978). Age determinations of alunite suggest two periods of formation: alunite associated with volcanic-epithermal veins is between 28 m.y. and 33 m.y. (McLemore, 1995); alunite associated with supergene alteration of porphyry copper deposits is 46.5 m.y., 39.5 m.y., 25.4 m.y., 16-19 m.y., and 8.4 m.y. (Cook, 1993; McLemore, 1995; S.S. Cook, personal commun., October 1994). The latter period suggests at least 5 supergene events.

As many as 15 alum mines were active in the Alum Mountain (Alunogen) district in 1885 (Clarke, 1884; Blake, 1894; Hayes, 1907; Northrop, 1959; Elston and others, 1965). One shipment of 1,000 lbs was reported in 1885. Deposits occur along the contact with probable Tertiary-age volcanic rocks. Alunogen and halotrichite were identified in surficial deposits (Northrop, 1959). Alunite and disseminated pyrite were identified in the Alum Mountain altered zone (Elston and others, 1965).

Only two areas in the Mimbres Resource Area contain large quantities of alunite and (or) alum --Alum Mountain and Steeple Rock districts.

Alunite and alum deposits in the Mimbres Resource Area, as in other localities in the U.S., are currently uneconomic. Technology needed to produce aluminum from alunite and alum is expensive, and the deposits contain many impurities. Nevertheless, since the U.S. imports all of

its required aluminum, the potential in the Mimbres Resource Area could change if foreign supplies are threatened or exhausted.

CALICHE

Caliche, a product of weathering in arid soils, predominates in carbonate-bearing surface sediment areas (where carbonate deposits are exposed), and also in areas where sediments overlie carbonate rocks. It is formed by downward–percolating surface and ground water, causing precipitation of carbonate cement in thick layers near the surface. Caliche is used by the oil and gas industry in east-central New Mexico where it is locally available for drill pad construction; in this region of New Mexico, there is a lack of sand and gravel. Caliche forms in surficial deposits in the Mimbres Resource Area as well, but is not typically utilized for aggregate because sand and gravel deposits, which are preferred, are generally present (see Langer and others, this volume).

Localized occurrences of caliche are widespread in the study area and may attain thicknesses of tens of meters. Caliche is present in sediments of the Palomas Basin floor, Uvas Valley (Clemons, 1979), and as caprock on the La Mesa and correlative surfaces in the southern Mimbres Resource Area. Some deposits have been quarried for local use as road metal (Hawley and others, 1969).

CLAY DEPOSITS

Clay material for industrial use includes any natural fine-grained earthy material, including clay, shale, and soil (Siemers and Austin, 1977). Diverse properties of various clay types render them useful in industrial applications: such properties include plasticity, refractoriness, absorbency, inertness, bonding strength, gel properties, and large ion-exchange capacity (Siemers and Austin, 1977). Clays are used to absorb impurities in the food and textile industries. Structural clay products (tiles, pipes, bricks, etc.) use common shales and clays that can be molded when wet. Impure clay materials are used in the manufacture of adobe.

Numerous deposits of shale and clay occur in the Mimbres Resource Area in Mesozoic and Paleozoic rocks (Austin and others, 1982). Clays present, in addition to common shale or clay deposits, include meerschaum, fire clay, kaolin, and bentonite clay deposits. Active operations in 1981-82, in the counties of Hidalgo, Luna, and Doña Ana, are shown for clay, shale, and fire clay.

The primary clay type found in Santa Fe Group soils and sediments is calcium montmorillonite, but sepiolite and attapulgite have also been reported (Vanden Huevel, 1966). Clay has been produced from beds of bentonitic clay from the Santa Fe Group near Hatch. Bentonite, an expandable clay, has an ability to form a gel in combination with water; as such, considerable demand exists for the clay in drilling applications. Demand for clay materials was

significant in the 1930s and 1940s when oil and gas discoveries were at a peak in New Mexico and Texas (Hawley and others, 1969).

Refractory clays (usually kaolin) are formed during weathering and alteration of volcanic deposits. As late as 1979, a fireclay deposit near Pratt was mined by Phelps Dodge Corporation for use in copper smelting; reported production was 1,500 short tons per year (Siemers and Austin, 1979). Fire clay occurs in the Muir district, southern Pyramid Mountains. Kaolinite occurs in various igneous rocks and in bedded tuffs that have been hydrothermally altered; such deposits are plentiful in the Mimbres Resource Area.

Meerschaum

Bush (1915) noted that the first discovery in the United States in 1875 of meerschaum (sepiolite) was near Sapillo Creek in northern Grant County (Northrop, 1959; Elston and others, 1965). Sepiolite is a hydrous silicate of magnesia having the composition $2MgO{\cdot}3SiO_2$, a specific gravity of about 2, and a hardness of 2.0-2.5 (Sterrett, 1908). This tough, porous, finely granular white mineral, which will float in water when dry, is a product of the alteration of magnesian rocks or minerals, generally magnesite or serpentinite. Samples collected by F.J. Kuellmer and examined by Weber consisted of crossfiber veinlets up to several cm wide that were shown to be nearly identical with those of a sepiolite standard from the classic deposits of Eski Shehr, Turkey.

Meerschaum is used in manufacturing smokers articles such as cigar holders, pipes, and pipe mouthpieces. Some meerschaum is used as an absorbent for nitroglycerine. Economic deposits of meerschaum are free of impurities and are mined in blocks from which pipes can be carved. Pipes manufactured from meerschaum may be very ornate, with clay, amber, wood, metals, and other materials added to heighten their commercial appeal. Lower-grade material is processed to free it of impurities and may be pressed or molded into shape, rather than carved (Talmadge and Wootton, 1937).

In the southern Alum Mountain district north and east of Copperas Creek, meershaum occurs in veins (**figure 7-7**). Sepiolite mineralization, which occurs in the Gila Conglomerate (Kuellmer, spoken commun. in 1958 to Elston and others, 1965) adjacent to the altered zone of Copperas Canyon, suggests that deposits are related to alteration and leaching of volcanic rocks. Vertical veins strike about N. 10° W., are 0.3-0.6 m wide, and about 300 m long. Veins of quartz and iceland spar occur near the meerschaum.

According to Bush (1915), intermittent production of meerschaum lasted from 1905 to about 1914, and was to be used in smoker's articles. Shipments from a mill on Sapillo Creek, 1-2 km from the mines, totalled an estimated 2 million lbs. A 1,000-lb shipment was made in 1943 for use in pipe liners and radio insulators (Northrop, 1959). Elston and others (1965) reported two

ruined shafts and several open cuts at the Sapillo Creek site. Talmage and Wootton (1937) describe these meerschaum deposits as vein deposits in Tertiary igneous rocks. Meerschaum occurs in the veins as impure nodules or as blocks up to a meter in width (**table 5-1.2**). Typically, meerschaum contains crystals of quartz or calcite, requiring washing to obtain the desired purity.

DIMENSION STONE, TRAVERTINE, CALCITE, and TALC

Dimension stone is used primarily in blocks, building construction, monuments, curbing and rubble (Siemers and Austin, 1978). Rock constituents used in dimension stone include sandstone, limestone, marble, igneous rock types, quartzite, and travertine. In the Mimbres Resource Area, flagstone is quarried in Luna County. Limestone and marble are produced from three quarries in Doña Ana County (Dupree and Eveleth, 1991).

At Cliff Roy Mine, Caprock mining district, banded travertine occurs with epithermal manganese and fluorite deposits. Extensive travertine deposits are present in the Antelope Wells-Dog Mountains district in the Bluff Creek Formation. Beds are about one m thick. Travertine deposits are thick enouth and extensive enouth to be quarried for local use at Goat Ridge, Fluorite Ridge mining district. Yellow and white travertine in beds up to 1.5 m thick occur on the southern slopes of the Tres Hermanas Mountains. Travertine deposits (previously described as marble) are present in the southern East Potrillo Mountains (sec 24, T. 28 S., R. 2 W.) and in the Rincon district. Radioactive travertine occurs at the base of San Diego Mountain, and was quarried from the Selden Hills (secs. 20, 21; T. 20 S., R. 1 W.). A small deposit is in northern Tortugas Mountain. Ornamental calcite is mined from the Cedar Hills (Rainbow Marble mine; Austin and others, 1982). Rainbow Marble mine produced a reported 90 cu ft of decorative marble per day from a travertine deposit near Radium Springs (Siemers and Austin, 1978).

Rhyolitic tuff was used as building stone, Silvertip district, Peloncillo Mountains.

Talc deposits are located in the San Andrecito-Hembrillo district in Precambrian granite and metamorphic rocks (see McLemore and Sutphin, this volume).

FLUORSPAR AND BARITE

by

Alan R. Wallace, USGS

and Virginia T. McLemore, NMBMMR

INTRODUCTION

Fluorite and barite are abundant in the Mimbres Resource Area, although commercial production has been insignificant (**table 7-4**). Both fluorite and barite are important industrial minerals with hundreds of commercial uses ranging from chemical to metallurgical (Brobst, 1994;

Fulton and Montgomery, 1994). Neither commodity is currently being produced from the Mimbres Resource Area.

Fluorspar and barite deposits of various sizes and grades are scattered throughout the four-county Mimbres Resource Area. Fluorite and barite deposits in the Mimbres area are listed in **table 1-5**; undeveloped small veins or extensions of known deposits are scattered throughout the area. Most of these workings produced only small amounts of ore (less than 500 short tons), if any, and only 11 mines produced a total of 10,000 short tons or more of fluorspar ore through 1978. Only one barite mine --Palm Park-- has produced any significant barite (Rincon district total = 10,250 short tons).

By comparison, total U.S. production of fluorspar in 1993 alone was 60,000 short tons, mostly from the Hick's Dome area, Illinois. China's 1993 production of 2.1 million short tons dwarfed U.S. production, and the U.S. imported nearly 500 million short tons of fluorspar in various forms in 1993. Therefore, although the deposits in the Mimbres area have been important locally during the history of mining in the area, the fluorite and barite deposits do not constitute a significant national resource. Because many of the districts and deposits have not been extensively explored, undiscovered deposits of regional significance, including that for local use in mills and smelters, may still be present (Shawe, 1976, p. 53).

Fluorite is a vital component in the manufacture of hydrofluoric acid and various associated products, which are required by the aluminum, fluorochemical, and uranium industries for processing. It is used as a flux by steel manufacturers and in the ceramic industry (Fulton and Montgomery, 1994). Most of the fluorite consumed in the United States is imported from Mexico and China (Fulton and Montgomery, 1994). A hydrofluoric acid plant is located in Juarez, Mexico, west of El Paso, Tex., and south of the Mimbres Resource Area.

Since 1926, the most important use of barite is in the oil and gas industry, where barite is used as a weighting agent in drilling muds to help control drill-hole pressures. In 1990, 90 percent of the barite produced was used by the petroleum industry (Brobst, 1994). Consequently, production of barite is dependent upon, and subject to the vagaries of, the petroleum industry. Barite is also used in the manufacture of barium chemicals and glass, as well as a filler, extender, and pigment (Brobst, 1994).

GEOLOGY

Despite their relative economic insignificance, fluorspar and barite deposits are of geologic interest because they reflect several different mineralizing environments that relate to the occurrence of other deposit types throughout the study area. Although not all of the fluorite and barite deposits can be categorized, many fall within four broad deposit types. Some deposits are simply

discontinuous veins with no outstanding definitive characteristics. The four deposit types discussed below include:

--deposits related to magmatic systems

--deposits related to volcanic hydrothermal systems

--deposits related to extension

--deposits related to sedimentary processes

Deposits Related to Magmatic Systems

During the formation of large magmatic systems, fluorite (rarely barite) may be deposited along fractures and faults along the fringes of the mineralizing system, or in more central areas as the mineralizing event wanes. Host-rock response to fluids varies with competency and carbonate content, producing vein or replacement deposits. If the core system subsequently is exposed, the zonal relationship between the two deposit types is evident. If the porphyry is too deeply buried to be identified, fluorspar deposits may be the only manifestation of the larger system and may not be distinguished from deposits formed by other processes. Conversely, exposure of the core of the porphyry system might indicate that distal fluorspar deposits have been eroded. Fluorite may also replace carbonate adjacent to magmatic systems. These deposits are termed skarns, and carbonate-hosted Pb-Zn and Ag deposits by North and McLemore (1986).

Due to the overlapping nature of mineralizing systems of different genesis and age in the Mimbres area, attribution of fluorspar deposits to this deposit type is difficult, except in rare cases where fluorite is intimately related to magmatic-related skarns. Truly felsic (rhyolitic) and alkalic igneous systems are more likely to produce fluorite deposits than calc-alkaline systems. Felsic and alkalic igneous systems are relatively rare in the study area, and the number of related deposits may be correspondingly small.

Deposits Related to Volcanic-Hydrothermal Systems

Volcanic systems, such as those found in the Animas Mountains and throughout much of the study area, commonly induce convective hydrothermal systems that can produce fluorspar with barite deposits, either in fractures within volcanic rocks, or in fractures within or replacing surrounding country rock. These deposits have been termed volcanic-epithermal deposits by North and McLemore (1986) and McLemore (1995).

Some deposits within volcanic rocks are the products of subsequent volcanic or other igneous activity. Fluorine can be derived as a volatile gas from magmas or can be leached from the surrounding country rock during hydrothermal convection; barium can also be leached from country rock during convection. However, not all volcanic rock-hosted deposits, such as the extension-related deposits described below, necessarily have a volcanic genesis, and attribution of

any particular deposit to volcanic processes may be difficult to impossible. Deposits of probable volcanic origin, including the Athena and Animas mines in Hidalgo County, are smaller than their porphyry-related counterparts, with production of as much as 7,000 short tons of fluorspar.

Deposits Related to Regional Extension

High heat flow and related hydrothermal convection in regional extensional settings, such as the Rio Grande rift and the Basin-and-Range province of southwestern New Mexico, can produce fluorspar deposits along fracture systems at shallow depth in virtually any type of host rock. This type of deposit has been termed sedimentary-hydrothermal barite-fluorite-galena deposits by North and McLemore (1986) and McLemore and Barker (1986).

Fault systems along the margins of uplifts, such as the Burro and Little Florida Mountains, are ideal sites for these mineralizing environments. Also, limestone or dolomite adjacent to deep-seated faults provides an excellent host for vein and replacement-type barite-fluorite deposits. Other favorable environments for fluorite and barite vein and replacement deposition includes highly fractured caldera margins, including the Bursum and Organ calderas, sites near the margins of younger uplifts, and locations within carbonate-rich sequences. Deposits of this type can rival the size of (but generally are smaller than) magmatic-related systems, and may be equivalent in size to the volcanic-hydrothermal deposits. Owing to the relative youth of these deposits and their shallow depth of formation, they have not been significantly modified or concealed by post-mineralization erosion or other processes. Their present distribution likely reflects the original foci of ore-forming processes.

Deposits Related to Sedimentary Processes

Sheppard and Mumford (1983) identified fluorite in ash-rich lacustrine sediments in the Miocene and Pliocene Gila Conglomerate east of Riverside in Grant County where fluorite occurs in fecal pellets derived from brine shrimp. Although the deposit is small and localized, it reflects a depositional environment within the relatively widespread Gila Conglomerate that may be present elsewhere within the Mimbres study area.

Origin and Setting

Many vein fluorspar and barite deposits in the Mimbres area are in fractures that are associated spatially with Tertiary dikes of felsic to mafic composition. This association may indicate that the fluorspar is related to magmatic (or subvolcanic) processes related to emplacement of the dikes. However, the dikes and the fluorspar-barite veins may be completely unrelated. Rather, their emplacement and formation may have taken place, perhaps at widely separate times, along preexisting fracture systems.

Regardless of origin, the majority of the fluorspar and barite deposits in the Mimbres area fill faults and fractures in competent, relatively non-reactive rocks such Proterozoic granite, felsic volcanic rocks, and clastic sedimentary rocks. Where mineralizing fluids reached Paleozoic carbonate rocks, fluorite and various gangue minerals partially to completely replaced the carbonate rocks. Therefore, in a broad, non-genetic classification, fluorspar and barite deposits fit into two general physical categories: fracture fillings in brittle rocks and replacement deposits in carbonate rocks. Fluorite, variously colored, typically forms fine-grained to coarse crystalline masses. Gangue mineralogy varies considerably, but important minerals include quartz, barite, calcite, galena, pyrite, and variable amounts of copper sulfides; trace elements include silver, lead, zinc, and gold. Mercury, arsenic, and antimony are uncommonly associated elements. Alteration haloes around individual veins are narrow, and include sericite, quartz, carbonates, barite, and pyrite. Jasperoid, either as a vein filling or as a replacement of country rock, is abundant in some deposits, especially in those with carbonate hosts. Barite locally exceeds fluorite in some deposits [e.g., Palm Park (Rincon district)].

Discussion of Assessed Tracts

For the purposes of mineral resource assessment of fluorspar and barite, known deposits were assessed by (1) geographic area, including discrete uplifts, and (or) (2) geographic concentrations of known deposits. Due to the high degree of prospector-scale exploration for these deposits, the absence of prospects in any given area effectively makes those areas unfavorable for the discovery of other deposits. However, the areas may be permissive for additional deposits due to the localized nature of fluorspar and barite deposits, and the 1-km depth consideration.

Tracts may include one or more deposit types, and the deposit type and its genesis were considered when evaluating each tract. Many individual deposits within tracts unfortunately could not be identified by deposit type, thereby negating the possibility of evaluating by deposit type. Where possible, the presence of identifiable deposit types in a tract was considered and subjectively extrapolated to other deposits of uncertain origin within the tract.

Gravity data delineated areas that were covered by more than 1 km of late Cenozoic deposits, and those areas were deemed unfavorable for fluorspar and barite deposits. Data for this assessment were derived from various previous assessments, including that for the Silver City 1˚x2˚ quadrangle (Richter and others, 1986), fluorspar investigations by Williams (1966) and McAnulty (1978), and field work related to the present study. Data on barite are from Williams and others (1964) and from field work related to the study.

Wilcox district

In the Wilcox district, fluorite (with rare barite) fills faults and fractures in middle Tertiary volcanic rocks at the southern margin of the Mogollon volcanic field. McAnulty (1978) reported four mines and prospects. Total production was 10,603 short tons of fluorspar, with 759 short tons from the Green Spar mine. Mineralization was structurally controlled by coincident pre-fluorite fractures related to the middle Tertiary Bursum caldera and to late Tertiary extension-related faults. With respect to the geochemical and geophysical characteristics of the district, the pre-fluorite, middle Tertiary mineralization has a masking effect, obscuring the geochemical evidence for fluorite mineralization. Undiscovered deposits are unlikely in the surrounding volcanic rocks, especially with increased distance from the extension-related faults along the late Tertiary Mangas trough several kilometers to the southwest. Deposits occurring at a distance from the trough probably would be concentrated along the southern margin of the Bursum caldera.

Gila district

In the Gila district, fluorite (with rare barite) fills faults and fractures in middle Tertiary volcanic rocks at the southern margin of the Mogollon volcanic field. McAnulty (1978) reports 14 mines and prospects in the district, 9 of which have reported production. Total production is 47,586 short tons fluorspar, and, of this, nearly 29,000 short tons came from Clum mine. The district lies along the northeast margin of the Mangas trench, a late Tertiary graben related to regional extension. The volcanic rocks are extensively altered, but McOwen (1993) demonstrates that fluorite mineralization is substantially younger than the middle Tertiary hydrothermal event that produced the alteration. Owing to the coincidence of middle Tertiary ore deposits, the effect of fluorite deposits on the geochemical and geophysical characteristics of the district are unknown. Many of the trace metals may be related to the earlier alteration and mineralizing system, but the aeroradiometric uranium high could be related to the fluorspar deposits.

The outline of the favorable tract is based upon the tight clustering of the known fluorite occurrences. Mineralization was structurally controlled by coincident pre-fluorite fractures related to the middle Tertiary Bursum caldera and to extension-related faults. Undiscovered deposits may be concealed in the adjacent Mangas graben to the southwest, where they may be covered by the Gila Conglomerate, but additional deposits are unlikely in the volcanic rocks to the north and east.

Alum Mountain district

Alum Mountain district lies on the south edge of the middle Tertiary Gila caldera. No fluorspar or barite deposits or occurrences have been reported from the area, but the area is considered permissive, owing to the presence of other epithermal mineral occurrences. However,

the shallow level of erosion relative to the other mineralized zones and the absence of reported occurrences despite the prospector-scale scrutiny that the area has received suggest that the area is not favorable for the occurrence of concentrated amounts of epithermal fluorite or barite.

Buckhorn area

Fluorite has been reported northwest of Silver City from a small area 2.4 km east of Buckhorn; no production has been reported. The fluorite is in zeolitic tuffs in a lacustrine facies of the late Tertiary Gila Conglomerate. Fluorite occurs as small epigenetic pellets that, in part, are of fecal origin, and it makes up 20-30 percent of the tuff at this occurrence (Sheppard and Mumpton, 1984). The source of the fluorine is unknown, but it may reflect the proximity of fluorine-rich deposits at the Gila and Wilcox districts, a scenario that may have been duplicated elsewhere in the study area near known fluorspar districts. The fluorite-rich unit is restricted locally, but the Gila Conglomerate is extensive throughout the Mimbres area. As a result, similar small occurrences may be present elsewhere in the study area, making the Gila Conglomerate a permissive host. Only in and around the Buckhorn area is the formation favorable for this type of deposit.

Steeple Rock district

The fluorspar mines of the Steeple Rock district are within an area of volcanic–epithermal mineral deposits related to middle Tertiary volcanic and igneous activity. Fluorspar is present in five mines and prospects, with a total production of 11,000 short tons of fluorspar, most of which came from the Mohawk mine (McAnulty, 1978; McLemore, 1993). Fluorspar fills fault zones primarily in Middle Tertiary volcanic rocks, with minor ore in rhyolitic rocks in the extreme southeast part of the district (Williams, 1966). Although the deposits permissively could be related to younger, nonvolcanic processes, the close relation between the fluorspar and precious- and base-metal deposits strongly suggests that they are part of the same middle Tertiary mineralizing system. McLemore (1993, 1994) suggests that the fluorite-barite veins form an outermost zone of lower-temperature fluids that surrounds the base- and precious-metal veins. At least two centers of fluid upwelling are apparent from fluid inclusion data (McLemore, 1993, 1994). However, considering the small size of the known deposits and the high level of exploration in the area, the potential for a large deposit is relatively low.

Pinos Altos-Santa Rita-Silver City area

Large Laramide porphyry copper systems with various types of cogenetic mineral deposits dominate the mineral deposits of the Pinos Altos-Santa Rita-Silver City areas. Fluorspar has been reported and mined from the Fleming district, with a total production of 232 short tons from three small mines (McAnulty, 1978). Host rocks at Fleming are Proterozoic granitic rocks and Paleozoic carbonate rocks, and ores fill fracture-controlled breccia zones primarily in the granitic

rocks (Williams, 1966). The origin of the Fleming deposits is equivocal: the deposits may be related to the porphyry systems at Copper Flat and Santa Rita, but the composition of those magmatic systems is not compatible with fluorite-rich fluids. Considering their proximity to the Mangas graben, they could be products of late Tertiary extension, similar to the Gila and Wilcox areas. The only reported fluorite occurrence related to the large Santa Rita porphyry system is as an accessory mineral in carbonate-hosted zinc skarns at the Pewabic mine (Schmitt, 1933); it has not been reported from other related deposits (Hernon and Jones, 1968).

Carpenter (Schwartz or Swartz) district

Fluorite and barite have been reported but not produced from the Carpenter district in easternmost Grant County; the area is on the margin of the middle Tertiary Emory caldera. The area produced silver, gold, and other commodities that are vein-filling and replacement deposits in Paleozoic sedimentary rocks. Fluorite is likely to be related to the larger mineralizing system and is therefore probably of middle Tertiary age. The absence of production, despite the high level of prospecting and the proximity of the end-use smelting facilities near Silver City, strongly suggests that fluorspar and barite are not present in significant quantities in this area. The district is permissive, but is not favorable, for fluorspar and barite resources.

Burro and Little Burro Mountains

The Burro and Little Burro Mountains contain a variety of hydrothermal fluorspar deposits, including those at the Burro Chief and Shrine mines near Tyrone; each of these deposits produced more than 71,000 short tons of fluorspar and represent the largest known fluorspar deposits in the Mimbres area. Most of the deposits in the central and southern Burro Mountains fill faults and fractures in granitic rocks of Proterozoic ages. Many are associated spatially with Eocene and Oligocene plutons, including the White Signal stock and related northeast-trending dikes (Drewes and others, 1985). Uranium, tin, and tungsten are anomalously abundant in the vicinity of these middle-Tertiary intrusive rocks, an association typical of evolved felsic magmatic systems. As a result, many of the fluorspar deposits may also be part of this magmatic suite. A number of deposits formed along range-front faults northeast of Redrock, and their genesis may be related to late Tertiary extension.

Thus, the Burro and Little Burro Mountains contain deposits that formed during two mineralizing epochs--an earlier Laramide episode and a later episode related to extension along the Rio Grande rift. Distinguishing between the two at most locales is difficult. Shrine and Burro Chief mines are proximal to the Laramide Tyrone porphyry copper deposit; but calc-alkaline magmatic systems, such as that responsible for the Tyrone deposit, typically do not produce fluorspar deposits. The deposits are more likely to be related to younger, superimposed

mineralizing events. Regardless of their genesis, the greater Burro-Little Burro Mountains area contains a known concentration of fluorspar deposits, and additional resources undoubtedly are present in undiscovered deposits or extensions of known deposits.

Pyramid, Animas, and Peloncillo Mountains

This tract includes the Lordsburg, Gillespie, Rincon, and Granite Gap districts; mines and prospects are listed in **table 5-2.13**, **table 5-2.3**, **table 5-2.10**, and **table 5-2.16**. Three mines in the Pyramid Mountains produced 9,591 short tons of fluorspar, most of which came from the Animas mine in the central part of the range. Small veins at the southern margin of the Lordsburg district cut Laramide mafic volcanic rocks and granodiorite (**table 5-2.15**). These deposits may be part of the larger Lordsburg base- and precious-metal mineralizing system. Athena mine is within early Tertiary volcanic rocks near the margin of the middle Tertiary Muir caldera in the west-central margin of the range, where it could be the product of middle Tertiary volcanic-hydrothermal activity or younger extension-related mineralization in a structurally favorable setting. The potential for significant undiscovered concentrations of fluorspar in this range is considered to be small.

Fluorspar has been reported from five mines and groups of prospects in the Winkler anticline in the north-central Animas Range. The Athena mine was the only producer and generated only 1,500 short tons of fluorspar. Fluorspar at the Athena mine replaces Paleozoic carbonate rocks and has abundant fluorite-bearing jasperoid bodies. McAnulty (1978) accredited the mineralization to the nearby middle Tertiary(?) Walnut Wells stock. Although the other prospects are relatively insignificant, additional resources may be present in and around the Athena mine. A mineral assessment of the area immediately south of the Winkler anticline indicated a low potential for fluorspar (Brooks and others, 1989).

Purple Star prospect is in the central Peloncillo Mountains, but no production has been reported. McAnulty (1978) reported that drilling in 1972 was not encouraging, and the area probably is not favorable for additional deposits. Minor amounts of fluorite have been reported from base- and precious-metal deposits in carbonate and volcanic rocks in the northern Peloncillo Mountains, but the area is not favorable for significant concentrations of fluorspar.

Sierra Rica-Little Hatchet Mountains

Base-metal deposits cut and replace Paleozoic sedimentary rocks and locally Tertiary volcanic rocks in the Little Hatchet Mountains, Sierra Rica, and Apache Hills (**table 5-2.18** and **table 5-2.3**). Small amounts of fluorite and barite have been reported from Apache Hills, but no production has been recorded. The fluorite is related to base-metal skarns and replacement deposits adjacent to an Oligocene stock.

Cookes Range-Fluorite Ridge

Cookes Range and Fluorite Ridge form an L-shaped uplift north of Deming that includes the Fluorite Ridge, Cookes Peak, and Northern Cookes Range districts. The majority of the mines and prospects are in the Fluorite Ridge area, where 10 mines and prospects have produced 87,533 short tons of fluorspar, with 76,000 short tons derived from the Greenleaf and Sadler mines (McAnulty, 1978) (**table 5-3.3**). Mineral prospects in the Cookes Peak district are listed in **table 5-3.4**. The deposits are in middle Tertiary granodiorite and Paleozoic limestone intruded by granodiorite; the rocks are overlain by Tertiary conglomerate. Fluorite Ridge, bearing many similarities to other extension-related deposits, is a relatively young, fault-bounded uplift, with the deposits filling faults oblique to the northwest trend of the ridge. McAnulty (1978) reported possible additional mining in the area, and none of the deposits have been completely mined out. Thus, the concentration of deposits and the possibility of extensions of known deposits makes this a favorable area for undiscovered fluorspar deposits. This area may extend 6 mi (10 km) to the northwest along the range front to the Goat Ridge prospect, where fluorite-rich jasperoids replace limestone and are associated with fluorite-bearing sinter indicative of a very shallow hot-spring environment.

Four mines in the northern Cookes Range have produced 63,983 short tons of fluorspar, virtually all from the White Eagle mine. Proterozoic granites, with minor Tertiary volcanic rocks, are the dominant host rocks. Middle Tertiary rhyolite dikes are common at the White Eagle mine, suggesting magmatic relations similar to that at the White Signal area of the central Burro Mountains. McAnulty (1978) considered this area to have large potential reserves, based upon the discovery of several blind veins at the White Eagle mine.

Florida-Little Florida Mountains

Fluorspar and barite have been identified at five mines and prospects in the Florida and Little Florida Mountains (**table 5-3.8**, **table 5-3.10**). Total production was 13,628 short tons of fluorspar, with all but 420 short tons from the Florida mine at the northeast margin of the Little Florida Mountains. Fluorspar ore at the Florida mine is in irregular fluorite–barite– quartz veins that cut poorly consolidated alluvial fan conglomerates that possibly overlie Gila Conglomerate. Other small mines and prospects explored veins and replacements in limestone (the Anniversary deposit filled solution cavities in limestone) and Tertiary volcanic rocks. The presence of ore in these three disparate settings, as well as barium anomalies in stream-sediment samples, suggests a favorable environment for additional similar types of deposits.

Tres Hermanas Mountains

Fluorite is only a trace occurrence in the Tres Hermanas Mountains (**table 5-3-13**), which is otherwise dominated by carbonate–hosted skarn deposits adjacent to an Eocene stock. Although permissive for additional fluorite deposits, the small amount present does not indicate favorability for significant concentrations of fluorspar.

Rincon-Tonuco-Doña Ana area

Rincon-Tonuco-Doña Ana tract consists of the Rincon, Tonuco, Iron Hill, and Doña Ana Mountains mining districts. Sedimentary-hydrothermal barite and fluorite vein deposits (see Sutphin, this volume) occur in the Silurian Fusselman Dolomite, stratigraphically below the Percha Shale (Devonian) in the Rincon district (**table 5-4.12**) and in Proterozoic rocks in the Tonuco district (**table 5-4.13**).

Palm Park deposit in the Rincon district is the largest barite deposit, with a production of 10,250 short tons of barite (Filsinger, 1988). Horseshoe deposit is smaller, but is similar to the Palm Park deposit. Typically, the remaining deposits in the Rincon district are small and discontinuous. Brecciated ore, banded ore, and veins are common textures. Jasperoid is common throughout the district. Manganese and iron oxides locally are pervasive.

Fluorite-barite veins in the Tonuco district occur along northwest-trending faults and fractures in Proterozoic rocks and as open-space fillings in the silicified Hayner Ranch Formation (Miocene). Fluorite production is reported as 7,720 short tons and barite production is reported as 200 short tons (**table 1-5**; Rothrock and others, 1946; Williams, 1966).

Beal vein is about 60-100 m long, less than 0.6 m wide, strikes N. 25˚ W., and dips 70˚ SW. Assays at the Beal claims indicate 21.4-38.7 percent CaF_2 and 28.1-49.2 percent $BaSO_4$ (NMBMMR unpubl. file data). Tonuco vein is 300 m long, less than 3 m wide, strikes N. 70˚ W., and dips 60˚ SW. A sample assayed 35.7 percent CaF_2 and 47.2 percent $BaSO_4$ (NMBMMR unpubl. file data). The veins consist of barite, quartz, calcite, iron and manganese oxides, and fluorite. Other veins typically are less than a foot wide and discontinuous. Stratigraphic relations indicate that the deposits in both districts are probably Miocene (Seager and others, 1971; Filsinger, 1988).

Drill data indicate that the Palm Park deposit contains 1.5 million short tons of ore grading 27 percent $BaSO_4$ with a specific gravity of 3.07 (Filsinger, 1988). Horseshoe deposit could contain as much as 50,000 short tons of 5-20 percent $BaSO_4$; Prickly Pear deposit could contain as much as 200,000 short tons of 5-25 percent $BaSO_4$ (Filsinger, 1988). Both of these deposits are thin (less than 1.5 m thick). These barite deposits are uneconomic at present, and would be mined

only if petroleum exploration increases the demand for barite drilling muds. However, the high whiteness and brightness of the barite is desired in certain paints and fillers, and the barite could be produced if these specialized markets were developed. Fluorite-barite reserves have not been calculated for Tonuco district. Based on the coincidence of the area with the Rio Grande rift, this tract is favorable for additional extension-related fluorspar and barite deposits in and around the margins of exposed bedrock.

Victorio district

Fluorite has been reported from the Victorio area (**table 5-3.14**), and it is hosted by Paleozoic carbonate rocks, which underlie much of the area. Polymetallic replacement deposits overlie part of a gravity high, and magnetic anomalies coincide with the deposits. Although occurrences are small, the presence of fluorite indicates that additional deposits may be present. However, the available data suggest that the area is not particularly favorable for large concentrations of fluorspar.

Tortuga Mountains-Bishop Cap

Tortuga Mountains and Bishop Cap, east and southeast of Las Cruces, respectively, lie at the intersection of the Rio Grande rift and the margin of the Organ Mountains caldera. As a result, the area has excellent structural ground preparation for fluorite and barite deposits and is coincident with both volcanic- and extension-related mineralizing settings. Fluorspar has been exploited at both areas, with a total production of 20,751 short tons at the Permian-hosted Tortugas mine and 150 short tons at the limestone-hosted Bishop Cap prospects. Barite is abundant locally at Bishop Cap. Mines and prospects for the Bishop Cap district are listed in **table 5-4.22**. The deposits closely resemble those known to be related to the Rio Grande rift, but the influence of older caldera-related mineralization cannot be discounted. Although the areas have been heavily prospected, and much of the intervening area is covered by Quaternary alluvium, the area is favorable for additional fluorspar deposits.

Carrizalillo Hills-Cedar Mountains Range

Fluorspar deposits or prospects have not been reported from this area, but the presence of epithermal mineral deposits makes this tract permissive for related fluorspar deposits. Barite occurs in trace amounts in many of the jasperoids.

Potrillo Mountains

East Potrillo Mountains consist of approximately 1,340 m of sedimentary and volcanic rocks ranging in age from Permian through Holocene (Bowers, 1960; Jenkins, 1977; Seager and Mack, 1994). Permian and Cretaceous sedimentary rocks crop out in the East Potrillo Mountains, which are surrounded by basaltic flows of Quaternary age. Sedimentary– hydrothermal

barite-fluorite deposits (see Sutphin, this volume) are present in limestones of Permian age, either the Hueco Limestone or the San Andres Formation (**table 5-4.3**; Jenkins, 1977; Seager and Mack, 1994). Jasperoid is common in areas of mineralized limestone and occurs as pods of varying sizes along faults, fractures, breccia zones, and bedding planes. The zones consist of quartz, calcite, barite, iron and manganese oxides, and trace amounts of galena, pyrite, sphalerite, malachite, and cerussite. Up to 30 percent barite is found locally; lesser amounts of fluorite are found. Textures are variable and include breccias, jigsaw-puzzle, xenomorphic, reticulated, granular, ribbon-rock (banded), and massive (Jenkins, 1977). The mineralizing system contained fluorite and barite and the tract is permissive for both, but is probably not favorable for large deposits.

San Andres, Organ, and Franklin Mountains

San Andres-Organ Mountains-Franklin Mountains tract consists of the San Andrecito–Hembrillo, San Andres Canyon, Bear Canyon, Black Mountain, Organ Mountains, and Northern Franklin Mountains districts. Barite and fluorite occur in all of these districts. Barite has been produced from the Bear Canyon district (50 t) and Organ Mountains district (600 t) and fluorite has been produced from the Black Mountain (1,100 short tons) and Organ Mountains (1,500 short tons) districts (**table 7-4**). Rocks exposed in the tract are Proterozoic granite, quartz–feldspar–mica schist, quartzite, amphibolite, phyllite, and talc schist, which are overlain by sedimentary rocks ranging in age from Paleozoic through Cenozoic. Cambrian to Cretaceous rocks are about 2,195 m thick (Kottlowski and Lemone, 1994). Organ Mountain batholith separates the San Andres Mountains from the northern Franklin Mountains, and provided a magma and heat source to the area.

San Andrecito-Hembrillo district is the northernmost district in the study area; mines and prospects are listed in **table 5-4.10**. The most extensive development is the Hembrillo Canyon group of prospects. Additional prospects also occur in Hospital Canyon and prospect pits are reported to occur along veins in Lost Man Canyon (Dunham, 1935; The Mining World, 4/23/1910, p. 868). These prospects were not located during this study. Hembrillo Canyon prospects in Hembrillo Canyon consist of two shafts--one 4 m deep and another 23-30 m deep--and two shallow prospect pits. The deposits may be part of the Lot OM-69 prospect described by Williams and others (1964); however, Williams and others (1964) place the Lot OM-69 prospect in sec. 10, T. 16 S., R. 3 E., instead of sec. 9. Reconnaissance investigation of section 10 for this study failed to locate additional veins or prospects. Hembrillo Canyon prospects consist of thin veins and small replacement bodies within a faulted block of Lead Camp Limestone (Seager, 1994). The deposit is less than 92 m long and consists of galena, barite, quartz, calcite, iron oxides, and

possibly traces of wulfenite in limestone host rocks. A sample of the Lot OM-69 prospect reportedly contained 77.8 percent $BaSO_4$, 14.8 percent SiO_2, and 0.3 percent $CaCO_3$ (Williams and others, 1964).

The deposit in the San Andres Canyon district in the central San Andres Mountains was discovered in 1900. It is a small, irregular, replacement body in dolomite of the Fusselman Formation proximal to a north-trending fault that strikes N. 15˚ W., and dips steeply to the west (Dunham, 1935; Bachman and Myers, 1963, 1969; Smith, 1981). The deposit is about 60 m long and up to 6 m wide (Dunham, 1935) and consists of barite, quartz, minor galena, calcite, iron oxides, and clay. Neither barite nor fluorite have been produced.

Sedimentary-hydrothermal deposits (see Sutphin, this volume) are scattered throughout the Bear Canyon and Black Mountain districts, north of the Organ Mountains district, (**table 5-4.5**, **table 5-4.6**). The deposits consist predominantly of veins, breccia cement, cavity-fillings, and minor irregular replacement deposits along faults, fractures, unconformities, and bedding planes in dolomitic limestone (Dunham, 1935; Williams and others, 1964; Bachman and Myers, 1969; Smith, 1981; McLemore, 1994). Percha Shale and Proterozoic granitic and metamorphic rocks may have acted as an impermeable cap for ascending mineralizing fluids. Barite, fluorite, calcite, and quartz are the predominant minerals in these deposits. Locally, galena, malachite, and wulfenite are present (C.W. Plumb, unpublished report, Nov. 1925, NMBMMR).

Fluorspar has been reported at four prospects in the Organ Mountains, and 400 short tons were produced at the Ruby (Hayner) mine. Host rocks include Paleozoic limestone and marble. The middle Tertiary Organ caldera and related magmatic systems are coincident with the western margin of the structurally younger Organ Mountains uplift. As a result, the area is favorable for both magmatic/volcanic- and extension-related fluorspar deposits. Ludington and others (1988) noted the similarities of these deposits to other extension-related deposits, but included the prospects in a tract that included deposits related to middle Tertiary hydrothermal deposits. One of the two major plu short tons related to the Organ caldera system is somewhat more silicic than the rest of the magmatic system, and permissively may have produced fluorspar veins (Stephen D. Ludington, USGS, spoken commun., 1995). Regardless of genesis, the area is favorable for additional fluorspar vein deposits. Mines and prospects are listed in **table 5-4.22**.

The deposits found in the Northern Franklin Mountains (**table 5-4.4**) are similar to the deposits found in the San Andres Mountains (San Andrecito-Hembrillo, San Andres Canyon, Bear Canyon, Black Mountain districts). The deposits are minor and no barite or fluorite production has occurred. Veins and replacements of lead, barite, fluorite, calcite, iron oxides, and quartz occur in dolomitic limestone of the Fusselman Formation. The largest vein is less than 1 m wide and about

60 m long. Breccia and jasperoid are common locally. The association with galena, carbonate hosts, and proximity to the Rio Grande Rift suggest that these deposits are the sedimentary-hydrothermal products of late Tertiary extension.

Other areas

The association of fluorspar and barite with a variety of localized mineralizing environments makes many of the exposed areas in the Mimbres study area permissive for undiscovered fluorspar resources, especially along the flanks of uplifts and beneath the late Tertiary and Quaternary sedimentary cover that flanks those horsts. This is particularly relevant to relatively young, extension-related deposits that formed along range-bounding faults, such as at the Gila district and Redrock area, and that are present in the sediments along the flanks of the uplifts, such as along the northeastern margin of the Little Florida Mountains. Therefore, all of these areas should be considered to be permissive for undiscovered fluorspar and barite deposits, although the size of any particular target is unknown.

Grade and Tonnage Model

Due to the equivocal genetic origin of many of the fluorspar deposits in the western United States and the study area in particular, producing a meaningful grade and tonnage model is not possible at this time. Thus, the deposits have not been assessed quantitatively.

GEMSTONES AND COLLECTIBLE MINERALS

Turquoise-- Turquoise (blue and green varieties) has been mined from volcanic deposits in the Eureka district and Santa Rita areas since prehistoric times. To many, turquoise is symbolic of the indigenous cultures in the southwestern United States, and is in high demand for use with silver in jewelry.

Jasper and Opal-- Jasper and opaline quartz are reported from the Antelope Wells-Dog Mountains mining districts.

Agate, Geodes-- In the Carrizalillo mining district, Carrizalillo Hills, agate has been produced. Agate, jasper, and geodes are for the taking at Rock Hound State Park, Luna County. Geodes are present in the Carrizalillo mining district, Carrizalillo Hills.

Onyx, lavender spurrite, fluorescent aragonite-- These collectible minerals are found in the Tres Hermanas mining district, Luna County. Spurrite is a rare purple mineral used as an ornamental stone. See McLemore and Sutphin, this volume.

GUANO

Bat guano deposits are present in a cave in the Antelope Wells-Dog Mountains mining district (sec. 16, T. 33 S., R. 14 W. (Reiter, 1980).

GYPSUM

Gypsum deposits, in order to be of significant economic importance, must be laterally extensive and at least 9 m thick. In addition, since they are strip-mined, deposits must have limited overburden. In the subsurface at depths below about 122 m, the calcium-sulfate mineral is anhydrite rather than gypsum.

Thus, gypsum (calcium sulfate; $CaSO_4 \cdot 2H_2O$) is related to anhydrite, the anhydrous phase of gypsum, and the grade of gypsum is related to the completeness of hydration process and by the percentage of other impurities within the gypsum bed. Gypsum is converted from anhydrite by surface exposure. To be of economic grade, gypsum must be about 92 percent hydrated calcium sulfate for most industrial applications. Deposits must be thick and laterally extensive with limited overburden to be minable, but it must also be economically transportable to the consumer (it must be within reasonable distance of population centers or transportation centers). Typical ore dimensions of a minable deposit range in thickness from 10 m to 50 m over an area of several square kilometers (Raup, 1991). Deposits are typically strip-mined. Bedded marine evaporites are the most typical sources for gypsum deposits.

Uncalcined gypsum (which contains interstitial water) is an important chemical additive in agricultural products (for breaking up alkaline soil, adding sulfur and to free fixed potassium and other elements to the soil, and as additive to animal feed). Uncalcined gypsum need not be of high purity, and need only be pulverized for use.

Calcined gypsum is an essential commodity in the building industry. Calcined gypsum (from which the chemically bound water is removed) makes up most of the consumption of gypsum. The most important use of gypsum is in the manufacture of wallboard. Calcined gypsum, because it is hydrous calcium sulfate, will recombine rapidly with water; this property makes it an important additive of quick-setting plasters (e.g., plaster of paris and stucco). Gypsum may also be used to manufacture sulfuric acid, ammonium sulfate, lime, hydrated lime, cement, and other compounds.

In the Mimbres Resource Area, gypsum deposits, many localized, occur in sedimentary deposits of Pennsylvanian, Permian, Lower Cretaceous, and Quaternary age (Weber and Kottlowski, 1959; Kottlowski, 1963) (**figure 7-8**; **figure 7-9**). Small occurrences of gypsum are present in the Pennsylvanian Panther Seep Formation, units of the Magdalena Group, the Permian Abo-Hueco rocks, Epitaph Dolomite, San Andres Formation, Tertiary redbeds and other sediments, and Quaternary deposits, especially dune and playa deposits (Logsdon, 1982). No deposits have been mined (Austin and others, 1982). Gypsum dune sands (99 percent gypsum)

comprise the dunes of White Sands National Monument in the northeast corner of Doña Ana County. These deposits are off-limits to mining.

PENNSYLVANIAN DEPOSITS

In the San Andres, Organ, and Franklin Mountains, and in the subsurface east of the ranges, the Panther Seep Formation (Magdalena Group) hosts gypsum deposits in two beds. The upper bed is 20-31 m thick, and locally grades in gypsiferous limestone with large gypsum nodules (Weber, and Kottlowski, 1959). The beds dip 25˚-30˚ to the west. They would probably be mined using underground methods; however, the deposits are within the White Sands Missile Range and the White Sands Wildlife Refuge, which precludes their development.

PERMIAN DEPOSITS

Gypsum deposits estimated to be as thick as 61-92 m are present in contorted beds of the Epitaph Dolomite on the southwest side of the Big Hatchet Mountains; the beds are part of numerous thrust sheets (Weber and Kottlowski, 1959; Drewes, 1991; Logsdon, 1982) extending for about 23 acres. The gypsum, containing 95 percent calcium (high purity) is banded and locally contains beds of dolomite that may be 15 cm thick. In Humble State No 1BA, an oil test well southwest of the Big Hatchet Mountains, thick anhydrite beds were encountered in the Epitaph Dolomite (Weber and Kottlowski, 1959).

The Yeso(?) Formation in the northern part of Doña Ana County may contain small deposits of gypsum.

LOWER CRETACEOUS DEPOSITS

Hell-to-Finish Formation, exposed in the foothills of the Big Hatchet Mountains, is a continental red-bed sequence that contains thick beds of gypsum in its lower part (Zeller, 1958; Drewes, 1991). Two beds of gypsum have been reported; they are interbedded with shale, sandstone, and calcarenite in the upper part of the Hell-to-Finish Formation. Maximum combined thickness of the two beds is 18 m, and they extend for about 0.4 km (Weber and Kottlowski, 1959).

TERTIARY DEPOSITS

According to Weber and Kottlowski (1959), gypsum deposits occur in the southern Robledo Mountains along Apache Canyon. Red beds typically contain laminae of gypsum that locally are as thick as 0.3-3.0 m. In one area near Apache Dam, a persistent pure gypsum bed, 0.6-1.2 m thick, occurs over 3-4 acres beneath 3-12 m of overburden. Gypsiferous beds are locally interbedded with tuff beds and overlie a basal limestone-boulder conglomerate. The gypsiferous beds, of unknown age, are presumed to be Tertiary (Weber and Kottlowski, 1959).

QUATERNARY DEPOSITS

Massive gypsum beds crop out near Lake Lucero (Tularosa Basin) in northeastern Doña Ana County; they probably formed by evaporation of near–surface waters and precipitation of caliche. The gypsum deposits that border Lake Lucero are precipitated by calcium–sulfate–saturated waters. The white sands of White Sands National Monument are composed of broken grains of gypsum that have been deposited by westerly winds that pick up grains of gypsum from the shores of Lake Lucero. A new supply is provided by the lake each year after the wet season. Only a small portion of the enormous gypsum resource in the dune deposits of White Sands National Monument occur in northeastern Doña Ana County, and these lie within the White Sands Missile Range, which precludes their development.

Gypsum is generally present in the fine-grained component of the Santa Fe Group sediments in the Jornada del Muerto and elsewhere in the study area.

IRON

by Daniel R. Hack, NMBMMR

Iron is an important ingredient during the smeltering of base and precious metals and in the manufacture of steel. In 1994, 58.2 million tonnes of iron ore was produced in the U.S., virtually all (57.8 million tonnes) from the Lake Superior area. Through March 1995, 19.2 million tonnes of iron had been consumed by the U.S. steel industry and 15.3 million tonnes was produced domestically (USBM, 1995).

The first known production of iron oxides in New Mexico was by Native Americans, who used the red and yellow ocher as pigment in paint. In the 1880s, iron ore was mined for metallurgical flux in the smelting of siliceous base- and precious-metal ores (Harrer, 1965). Most of state's iron ore production from 1889-1899 (234,000 short tons) was shipped to the Colorado Fuel and Iron Corporation blast furnaces in Pueblo, Colorado.

Compared to national production, iron production in New Mexico is small, amounting to less than 8.2 million short tons through 1962 (Harrer and Kelly, 1963), and negligible production since. Most production is from Grant County, totalling 5.5 million short tons of magnetite, with 35-55 percent contained Fe from the Fierro-Hanover district (the largest producers being the Republic, Jim Fair, and Snowflake mines) and 2.7 million short tons of manganiferous iron ore, with 30-40 percent contained Fe and 10-13 percent contained Mn from the Boston Hill mines in the Chloride Flat district near Silver City (Harrer and Kelly, 1963). Total reported production from the study area is estimated at 8.2 million short tons of ore (**table 1-7**). Historic sporadic production from the Santa Rita, Pinos Altos, and Iron Hill districts was not reported.

IRON OCCURRENCES AND DEPOSIT TYPES

The most productive iron deposits in the study area are contact pyrometasomatic bodies in Paleozoic sedimentary rocks associated with Laramide intrusives. In the Fierro-Hanover district, skarn deposits of magnetite and hematite have been developed where the Hanover-Fierro granodiorite stock and adjacent dikes and sills contact Paleozoic calcareous and dolomitic sedimentary rocks. In the vicinity of the Santa Rita district, non-magnesian limestone of the Oswaldo Formation is replaced by disseminated magnetite near contacts with the Santa Rita stock. At Soledad Canyon in the Organ Mountains, small, discontinuous deposits of magnetite-hematite and ilmenite occur as replacement deposits where limestone is in contact with monzonite. Similar deposits are found about 1.5 km north in Rucker Canyon (Harrer and Kelly, 1963). At a prospect pit in the McGhee Peak subdistrict, Peloncillo Mountains, replacement-iron deposits are present in limestone. Replacement-iron deposits in limestone host rock associated with an intrusive monzonite porphyry are present in the Tres Hermanas Mountains (Harrer and Kelly, 1963).

Carbonate-hosted manganiferous hematite deposits in the Chloride Flat district in Grant County were major producers, occurring in fractured, shattered, calcareous sedimentary rock near the Silver City quartz-monzonite stock. Mesitite, a variety of magnesite, along with specularite and magnetite were deposited by hydrothermal solutions, and enriched by supergene processes. Copiapo Mine in the Franklin Mountains, another supergene deposit, is located where jarosite, minor limonite, and malachite exist in sheared Magdalena limestone (Harrer and Kelley, 1963). Mineral pigment was mined prior to 1946 from a 60-m inclined shaft with levels. At Mineral Mountain in the Lone Mountain district, manganiferous hematite, with some pyrolusite and magnetite, is present as irregular masses in shattered limestone (Harrer and Kelley, 1963). However, at the American claims in the Florida Mountains district, manganifeous hematite and limonite occur as small veins in fanglomerate.

Throughout the study area, sedimentary iron deposits have een of local importance, but production was negligible. Between Sycamore and Bear Creeks in the Piños Altos district, syngenetic oolitic hematite is exposed for a length of over 2,438 m in the Bliss Formation. Reserves have been inferred at 5 million short tons of ore having 25 percent contained Fe, but there has been no production (Harrer and Kelley, 1963). In the San Andres Mountains, disseminated oolitic hematite is present in 2 thin sandstone beds of the Bliss. There has been no production (Harrer and Kelley, 1963).

Igneous-hosted iron deposits are rare in the study area, the noted exception is in the Little Hatchet Mountains where disseminated and vein-controlled specularite and magnetite occur in Tertiary volcanic rocks (Harrer and Kelley, 1963). A small Precambrian deposit is found in

metamorphosed rocks in the northern Big Burro Mountains, Ricolite district; there, small lenticular bodies of magnetite occur in banded spepentine (Kelley, 1949).

Exploitation of iron deposits in the study area is hindered by the lack of steel mills within an economically viable distance. Iron ore has potential use as railroad ballast.

JAROSITE

by Virginia McLemore, NMBMMR

Copiapo jaoriste mine is located in the Northern Franklin Mountains at Webb Gap (NE sec 8, T. 26 S., R. 4 E.). Development consists of a 200-ft inclined shaft with four levels and six prospect pits. Several hundred tons of material were mined from 1925 to 1928 by F.Schneider Co. for use as pigment in paints.

The deposit occurs along a north-trending, low-angle fault zone (N. 10˚ E., 40˚-50˚ E) within the Bishop Cap Formation, Magdalena Group. At the shaft, the deposit is 10-15 ft in width and approximately 100-200 ft long. The deposit pinches out to the north; a drift at the 100-ft level is 20 ft long to the north and 100 ft long to the south (Dunham, 1935). The deposit thins to the south (<10 ft wide) for approximately 1,000 ft. The host limestone strikes N. 13˚ W., and dips 40˚ W.

The deposit is a vein or replacement deposit along the fault zone. It consists of jarosite (red to yellow to orange), limonite, hematite (red to black to brown) gypsum, calcite, and aragonite. Malachite stains are reported coating fractures at the bottom of the shaft (Dunham, 1935). Jarosite occurs only within the upper 35 m (unpublished data; files of the New Mexico Bureau of Mines and Mineral Resources). A crude zonation is present. The zone adjacent to the footwall consists of black to dark brown hematite and limonite and is approximately 1-2 ft wide. Jarosite, limonite, and hematite of various colors forms the central zone and ranges in thickness from 2 to 10 ft. The outer zone, adjacent to the hanging wall, consists of white calcareous to clayey material with zones of hematite and jarosite that cut it.

The origin of the deposit is speculative; the minerals are poorly crystalline to very-fine grained and unconsolidated, and are crudely zoned, suggestive of a supergene origin (sulfur-isotope analyses are required for confirmation). Possibly the deposit overlies epithermal base or precious metal deposits, but drilling would be required to verify their presence. The economic potential for future use as paint pigment is probably low, owing to the small size of the deposit and its considerable distance from paint manufacturers. Localized small (uneconomical) occurrences of jarosite, limonite, and hematite that are predominantly fracture coatings occur throughout the limestone deposits in sections 22 and 27, T. 26 S., R. 4 E.

MANGANESE

by Daniel R. Hack, NMBMMR

Historically, manganese has been an important commodity for industry in nonmetallurgical applications, such as in the production of dry cell batteries, plant fertilizers, animal feed, and as a brick colorant (Jones, 1992). The primary use of manganese is as a desulfurizer and deoxidizer in steel manufacturing, each short ton of steel requiring 13-15 lbs of manganese (Dorr, 1963).

The earliest use of manganiferous ore in New Mexico was as a flux in lead and copper smelters. An estimated 87,000 short tons of manganiferous ores were produced in the 1890s through 1907, when the smelters closed (Farnham, 1961). Manganese ore and manganiferous iron ore for use in the steel industry were shipped beginning in 1916. Total reported production of ore from the study area is 1,664,660 short tons, including about 1,635,000 short tons of manganiferous iron ore and 25,582 tons concentrate from the Chloride Flat district (**table 1-9**).

During World War II, with the realization of manganese as an important war-time commodity, the Metals Reserve Company established a manganese-purchasing depot at Deming to stimulate domestic production. In 1951, the General Services Administration (GSA) reopened the depot, purchasing ore containing not less than 15 percent Mn for $2.30 per long ton unit (22.4 pounds) of recoverable manganese (Farnham, 1961). The bulk of manganese production from the Mimbres Resource Area occurred at this time. The depot received 47,013 long tons of ore and 113,428 long tons of concentrates from New Mexico before closing in 1955. After the closure of the Deming depot, shippers took advantage of the GSA's "carload-lot" program, which required a minimum manganese content of 40 percent (Farnham, 1961).

Occurrences

Manganese occurrences are found throughout the study area, and many of the mining districts, such as those at Caprock Mountain and Little Florida Mountains, are recognized as chiefly being manganese districts. Most of the deposits are of the epithermal type and closely related to volcanism. Typical of the district, the Manganese Valley mine in the Little Florida Mountains district southeast of Deming contains manganese along veins occupying fault fissures in consolidated beds of fanglomerate. This mine was responsible for nearly 80 percent of Luna County production, and the Little Florida Mountains district as a whole accounted for 93 percent of total output (Farnham, 1961). At the Cliff Roy and Consolation mines in the Caprock Mountain district, hard psilomelane occurs in steeply dipping fault and fracture zones in volcanic agglomerate (Pradhan and Singh, 1960), and at the Burris claims on the east flank of the Little Burro Mountains, pyrolusite and wad occur in fractured fanglomerate.

Several minor manganese deposits in Grant County are associated with igneous units. At the Manhattan and Pleasant View claims in the Bayard district, manganese oxides associated with sphalerite, galena, and cerussite are found along a fissure zone in quartz diorite porphyry (Farnham, 1961). At the Black Eagle claims in the Ricolite district, ore occurs in a well-defined vein at the contact of a coarse-grained granite and volcanic rock. At the Black Tower, Hillside, and Old Smokey claims, manganese is associated with fractures in intrusive and extrusive rocks. Last Chance deposit in the Rincon district is associated with fractures in volcanics (Farnham, 1961).

With the exception of the Kuykendall property west of Animas, all Hidalgo County deposits occur in fractured and brecciated zones in volcanic rock (Farnham, 1961). At the Black Face claims north of Steins, manganese occurs in a broad, brecciated shear zone in rhyolite porphyry, and at the Amy K claims north of Rodeo, ore occurs along a brecciated shear zone in andesite porphyry (Farnham, 1961). All Hidalgo County deposits are small, and both production and reserves are believed to be insignificant (Farnham, 1961).

Not including the Little Florida Mountains district and the carbonate-hosted Birchfield claims, manganese deposits in Luna County are associated with faults, fissures, and fractures in volcanic and other igneous rocks. At the Southside claims in the Florida Mountains district, manganiferous calcite veins occur along fissures cutting granitic rocks, and at the Iron Clad claims in the Cookes Range District (the most productive deposit), about 104 long tons of ore were shipped in the 1950s; ore was found along a vein in porphyritic volcanic host rock.

A significant number of manganese deposits in the study area are associated with carbonaceous rocks, both as fracture fillings and as replacement bodies. In the Lone Mountain district at Mineral Mountain, pyrolusite and wad occur in irregular, disconnected pods in fracture zones cutting Carboniferous limestone. At the Blackie claims in the Rincon district, psilomelane with minor pyrolusite and wad are associated with fissures cutting Paleozoic beds of gray cherty limestone (Farnham, 1961). At Kuykendall property in Hidalgo County, ore occurs in stringers and bunches along a fracture zone in massive Paleozoic limestone.

Manganiferous iron ore at Boston Hill and Chloride Flat are responsible for nearly 1.7 million short tons of fluxing ore from 1883 through 1959; the ore occurs as intimate mixtures of hematite and pyrolusite in irregular bodies replacing gently dipping dolomite of the El Paso, Montoya, and Fusselman units. At Bear Mountain Group, Fleming district, pyrolusite and wad occurs in irregular disconnected lenses replacing several superimposed beds of Carboniferous limestone. An estimated 1,830 tonnes of ore was produced until 1959. At the Birchfield claims, Florida Mountains district, pyrolusite, wad, and psilomelane occur as small irregular replacement deposits in beds of Paleozoic limestone (Farnham, 1961).

There has been no appreciable domestic production of manganese since the 1960s, and no production in the Mimbres Resource Area since the end of GSA's "carload-lot" program in the early 1960s. Most of the estimated remaining reserves amount to only a few hundred to a few thousand short tons (Farnham, 1961). These deposits cannot compete economically with the large, high-grade, manganese-oxide sedimentary and carbonate deposits that are currently mined in South America and the former Soviet Union.

MARBLE

by V.J. McLemore, NMBMMR

A marble occurrence is found in the southern end of the East Potrillo Mountains (sec. 24, E. 28 S., R. 2 W.). The deposit is developed by a small quarry (Approximately 300-400 ft long and 100 ft wide) and a shore decline (15 ft long). Production is unknown but presumed small because of the small size of the quarry. A stockpile of marble mixed with limestone and calcareous soil remains at the site in 1993.

The marble, recrystallized limestone of the Hueco Formation (Hoffer, 1976; Seager and Mack, in press), is white with thin black bands (up to several cm wide). The host limestone strikes N. 10˚ W. and dips 25˚ W. Most marble occurs as small pods or blocks that are fractured and broken; the largest slabs are only a few ft wide. The marble occurs along the range-bounding fault (Robledo fault of Hoffer, 1976).

The resource potential of this occurrence int he East Potrillo Mountains is low under current economic conditions. The marble deposit is too small and too fractured to have any major potential as dimension stone.

Marble also occurs locally along the intrusive contact between limestone and rhyolite and quartz monzonite porphyry north of Organ (Seager, 1981; Dunham, 1935). The marble is typically white and locally contains disseminations of pyrite, garnet, and epidote. One of the largest deposits is at the Hilltop mine where the adit penetrates approximately 300 ft of white marble interbedded with unaltered limestone (field reconnaissance, October 1993).

The resource potential of the marble deposits is low owing to their small size, distance to potential markets, and location within the White Sands Missile Range.

PERLITE

by James M. Barker, NMBMMR, and

Ernest F. Scharkan, Dennis Engineering, Socorro

Perlite, a hydrated siliceous glass produced by volcano-magmatic processes associated with Tertiary and Quaternary rhyolitic volcanism, includes any volcanic glass that will expand appreciably by stream-driven vesiculation (Weber and Austin, 1982, Austin and Barker, 1993).

This commodity is found in the glassy portions of silicic domes and flows, vitric tephra, chilled margins of dikes and sills, and welded ash-flow tuffs; extensive occurrences of perlite plus obsidian and pitchstone, deposits are probably present in the Mogollon–Datil volcanic field of southwest New Mexico.

"Onionskin" perlite, or classical perlite, has a pearly luster and abundant concentric fractures. Commercial grade perlite is any volcanic material that contains 2–5% H_2O as molecular water and hydroxyions (Austin and Barker, 1993). Hydration of the deposits probably took place by magmatic or meteoric water during or shortly after emplacement. Hydration can occur from magmatic water exsolved during cooling of the ash deposits (Friedman and Smith, 1958; Friedman and others, 1966; Taylor, 1968). Vaporization of this interstitial water during rapid heating to temperatures in the softening range for silica (760°–1100°C) results in vesiculation and expansion ("popping"). Vesiculation produces expanded perlite, a frothy glass product used in plaster and concrete aggregate, horticultural applications, fillers and extenders, filter aids, and cryogenic insulation. Expansion can range from 10 to 20 times the original volume. Some obsidian (0–2 wt% H_2O) and pitchstone (greater than 5 wt% H_2O) also bloat or expand under appropriate heat treatment. Usefulness of any perlite product is determined by the density, size distribution, and nonexpansible content of the expanded perlite. In 1992, construction uses of expanded perlite accounted for 66 percent of total domestic sales; use as filter aids accounted for 15 percent, and all other markets accounted for 19 percent (Austin and Barker, 1993).

In 1992, the U.S. produced approximately 571,000 st of perlite (about 80–90 percent of U.S. production), mostly from central and north-central New Mexico (Austin and Barker, 1993). No Agua Peaks on the Taos Plateau is the world's largest commercial-grade deposit; it is currently mined by Dicaperl Corporation (the perlite mining unit of Grefco, Inc.), and Harborlite Corporation. Perlite is also produced near Socorro (Dicaperl Corporation) and northeast of Grants (U.S. Gypsum Company). The most common form of perlite currently mined in New Mexico is granular or pumiceous perlite. This is generally mined with rippers and scrapers; onionskin perlite may require blasting prior to removal. U.S. apparent consumption of crude perlite in 1992 was 591,000 st. This production had a value of $15.3 million (Austin and Barker, 1993). In 1992, perlite exports were primarily to Canada, and were estimated at 30,000 st; imports, mostly from Greece, are an estimated 50,000 st (Austin and Barker, 1993).

Perlite occurs within the Mimbres Resource Area, but is not currently being mined. Three known occurrences of perlite near Silver City in Grant County have been described by Scharkan (1992) the Swartz, McDonald Ranch, and Wallace Ranch perlite occurrences (**figure 7-10**). Details of the laboratory analyses and field studies are in Scharkan (1992) and are not elaborated

herein. Laboratory testing includes brightness and expandability (furnace) testing, sieve analyses, SEM (scanning-electron microscope) and x-ray fluorescence spectrometry examination, and geochemical and isotope analysis.

Swartz occurrence

Perlite-bearing exposures are in sec. 34, T18S R10W, and sec. 3, T19S R10W southwest of Tom Brown canyon, east of Swartz, about 1.8 km west of NM State Hwy 61, and about 25 km northeast of City of Rocks State Park. Perlite units crop out on the hillside for about 2 km parallel to Tom Brown Canyon at elevations of 5,376–6,084 ft (USGS Faywood 7.5 minute topographic map).

Swartz area is dominated by Tertiary volcanic rocks, which have been subdivided into lower and upper volcanic sequences by Elston (1957). The lower sequence is a calcalkaline eruptive suite that grades upward from andesite to latite, and finally to rhyolite (Elston, 1957). Units include the Rubio Peak Formation, Sugarlump Tuff, Kneeling Nun Tuff, Mimbres Peak Formation (containing significant perlite horizons), Box Canyon rhyolite tuff, Rustler Canyon basalt, Caballo Blanco tuff, and the Razorback Formation, containing black perlitic glass and a spherulitic zone (Scharkan, 1992). The upper sequence is composed, from base to top, of andesite, trachytic rhyolite, basalt (flows, breccia, agglomerate, conglomerate, and sandy tuff), and rhyolite; units include Bear Springs basalt and Swartz rhyolite. Santa Fe Group and recent clastic units overlie the upper sequence.

Three perlite occurrences in the area trend N30°W, N72°W, and N55°E. Two perlite horizon are apparently related to the overlying Mimbres Peak rhyolite; the third perlite is genetically associated with an adjacent lithic tuff. The N72°W and N55°E exposures are part of a continuous perlite horizon (Scharkan, 1992). Field relations suggest that the perlite is a chill margin of Mimbres Peak Formation rhyolite. The perlite is 95–97 percent glass and contains no traces of large vesicles or glass shards implying, a rhyolite glass extrusion of rhyolite flow margin and not a water-rich, pumiceous (welded tuff) origin (Scharkan, 1992).

All Swartz samples have furnace yields (which shows the degree of expansion) equal to commercial deposits in New Mexico (GREFCO No Agua standard samples), but other physical testing results of these samples indicate they include both perlite and welded tuff samples. Brightness (a measure of whiteness necessary for some applications) of Swartz perlite samples is 22 percent below the GREFCO No Agua standard and is highly variable locally; samples have higher iron content than McDonald Ranch or Wallace Ranch samples.

McDonald Ranch occurrences

Perlite exposures are in sec. 1, 11, 12, and 13 T22S R15W and sec. 18, T22S R14W, 26 km north of US Interstate 10 on Highway 189. The perlite crops out along a 4-km trend on the northeast margin of Burro Cienaga. Perlite units crop out at elevations of 5,150-5,542 (USGA Werney Hill and Soldiers Farewell Hill 7.5 minute topographic maps). The region is cut by numerous small drainages that extend southwest into intermittent Burro Cienaga.

McDonald Ranch area is dominated by Tertiary volcanic rocks that are composed of, from base to top, rhyolite tuff, andesitic flow and tuff, rhyolite breccia, and intrusive andesite deposits. Rhyolite tuffs, the oldest rocks in the sequence, can reach 90 m in thickness, and contain perlite that originated at Morrow Ranch about 5.5 km northwest of McDonald Ranch (Ballman, 1960). According to Hedlund (1978), the rhyolite dome of Burro Cienaga, the source of the perlite, is an eroded feature; perlite forms a lens within the dome (Ballman, 1960). Perlite is exposed along the Flat Canyon and White Rock Canyon faults and smaller faults in the McDonald Ranch area. Tertiary volcanic and intrusive rocks are overlain by Gila conglomerate and Recent fanglomerates.

Perlite is variable and highly irregular within the rhyolite tuffs and flows. The horizon is approximately 92 m thick on either end of the "lens", and thins in the central portion; the exposure extends along strike for about 2 km. Along Burro Cienaga, perlite ranges from 1 to 92 m thick. A prospect pit is located at the thickest portion of the exposure beneath a felsic core (Scharkan, 1992). The thick perlite outcrop on the north end may represent a portion of a rhyolite chill margin or rhyolite glass flow derived from the rhyolite dome of Burro Cienaga 2 km to the northwest, or from a closer extrusive center such as the dome-flow complex mapped by Hedlund (1978) and discussed by Weber and Austin (1982). The thick perlite at the southern margin is related to local extrusion of the Burro Cienaga dome-complex (Hedlund, 1978). Pink felsic core occurs between lower perlite horizons and upper perlite horizons; the core thickness to the southeast, indicating the direction of the extrusive center. The perlite is 99 percent glass and contains no traces of large vesicles or glass shards [indicating a water-rich extrusion (Naert, 1974)] typical of economic deposits at No Agua Peaks and Socorro.

Test samples from McDonald Ranch have furnace yields and sieve analyses (showing the size range in expanded perlite and the size pattern for unexpanded grains) similar to samples from commercial deposits (GREFCO samples); however, brightness of the McDonald Ranch perlite is less than the standard (Scharkan, 1992). The amount of nonexpansibles in the samples varies locally.

Wallace Ranch occurrence

Perlite is exposed in sec. 19, T16S, R18W, on the hillside adjacent to Pine Canyon at

elevations of 5,600–6,020 ft (USGS Antelope Ridge 7.5 minute topographic map). Many intermittent drainages reach into Pine Canyon and Rock House Canyon.

Finnell (1987) and Hahman (1989) mapped the Wallace Ranch area. the area is dominated by interlayered Tertiary extrusive units including andesite flows, basalt flows, quartz latite ash flows, and rhyolite tuffs, flows, and intrusive equivalents. Volcanic units include, from base to top, the Datil Formation (2,745 m thick), an unnamed latite unit, basalt and basaltic andesite, Gila Conglomerate, and rhyolite, which contains a perlite facies. The units are capped by Recent bouldery gravel deposits and fans. Wallace Ranch perlite occurrence, which was described by Finnell (1987) and assessed by Hahman (1989), is associated with the upper rhyolite formation, which reaches a thickness of 61 m and belongs to the Sycamore Camp Rhyolite Series of Finnell (1987).

Perlite breccia and classical perlite are exposed below flow-banded rhyolite on hillsides surrounding Pine Canyon (finnell, 1987; Hahman, 1989; Scharkan, 1992); the bulk of perlite reserves are associated with granular perlite breccia (origin unknown). Lenses of granular perlite breccia are 4.6–18.3 m thick and are overlain by flow-banded rhyolite that can read 98 m in thickness. The lenses grade laterally into siliceous, glassy rhyolite tuff (Hahman, 1989). Rhyolite is always present above the classical perlite.

The three perlite lithologies present at Wallace Ranch are contemporaneous, being deposited during a single extrusive event. The breccia is an auto-brecciated remnant of a brittle, expanding exterior margin of an extrusive mass (Whitson, 1982). Overlying rhyolite represents the interior devitrified felsite exposed by complete erosion of the uppermost chill margin (Scharkan, 1992).

Classical perlite at this locality contains 99 percent flow-textured glass. Lack of relict glass shards indicate a non-welded tuff origin. Granular texture of the breccia suggests vesiculation during extrusion of the glass. Water possibly came from either magmatic or meteoric sources at shallow depth prior to, or during, emplacement (Weber and Austin, 1982). Furnace yields of the Wallace Ranch samples are 4 percent less than the GREFCO standard, and are variable locally. Wallace Ranch samples have variable degrees of brightness, ranging from 68 percent to 45 percent resulting from the iron-oxide content of volcnaic lithic grains.

Economic considerations

Perlite has a low unit value so an economic evaluation must consider location, access, physical and chemical characteristics of expanded perlite, market, transportation, and competition.

The nearest perlite production occurs at the Socorro Dicaperl pit, where sufficient proven reserves will last into the middle of the next century (Jenkins, 1989). Ease of mining and transportation are proven at this deposit.

An adequate source of electricity for a mill and transportation access do not currently exist near the McDonald Ranch occurrence. Impurities in the northern deposits render them unacceptable for mining. Minable reserves are restricted to the southern deposit; these are estimated to contain 6.8 million short tons of perlite (not sufficient to justify capital investment of a large, high-capacity mill). On-site crushing and screening would be required prior to shipping to a finishing mill. Brightness of perlite samples at McDonald Ranch is less than that of the Dicaperl (No Agua) standard and would limit usefulness of the final product. Recovery would extend to depths of 24 m, which is below the current water table (ground surface at Burro Cienaga), requiring pumping. Perlite from southern McDonald Ranch occurrence is possibly commercial.

Highway and rail construction would be required to develop perlite in the Swartz area. Power for a mill would have to be brought a short distance from NM Highway 61. One deposit of perlite at Swartz is of commercial quality, and has minable reserves (without overburden) of 1.85 million st. An additional 617,700 st of perlite could be mined by stripping 1.6 million st of rhyolite (overall stripping ratio of 0.65/1.00). Total reserves of 2.48 million st will not justify capital expenditure for a high-capacity mill, but a small, portable crushing and screening plant could rough-size the perlite prior to shipment to a finishing mill. Perlite from the thick lens trending N55E has properties of a commercial perlite, with an end-use limited by variable expanded densities and low brightness values.

No access, transportation, or electrical amenities are available in nearby areas for the Wallace Ranch deposit. In addition, the deposits are smaller, of more inconsistent quality, and are more difficult to extract than earlier-described occurrences. Classical perlite and granular perlite breccia reserves are estimated to be 68.15 million st. Rhyolite overburden is 45.4 millions tons. Open pit operations would be necessary to recover all reserves, Water would have to be continuously pumped form the deposit if it extends below the 5,600 ft level. This perlite reserve may not justify expenditure of capital for a high capacity mill. Nonetheless, granular perlite breccia and classical perlite form the area have physical properties of commercial perlite with potential end-uses limited by variable expanded density and brightness values. Testing of core samples from drill holes in the region obtained by Hahaman (1989) are described by Scharkan (1992), and show minor perlite potential at depth.

None of the three occurrences are sufficient to mine currently; dominance of the No Agua Peaks and nearby Socorro deposits, render them uneconomical. Expanded perlite physical

characteristics from the occurrences are variable, do not have consistent specifications, and limit the end-use marketability. Their remote location and poor accessibility detract further from the economic value of each.

RICOLITE

Ricolite is valued because of its color, peculiar banded and mottled texture, and the ease with which it is carved or polished (Hewitt, 1959). It has limited use for jewelry, bookends, paperweights, and other small lapidary objects, such as beads, pen stands, and bolas. It is collected today for lapidary use. Quality specimens can be polished, but its softness limits its use.

Ricolite was quarried in Ash Creek Canyon in the late 1800s and 1940s. The occurrence is in the Ricolite mining district, Grant County, where it occurs in the Ash Creek series metamorphic granite and metadiabase (see McLemore and others, this volume). Colors include green-yellow to very dark green, red, yellow, blue, and brown.

SCORIA AND PUMICE

by Virginia T. McLemore, NMBMMR

Scoria (volcanic cinder) and pumice (pumicite) are distinct types of pyroclastic deposits formed as volcanic fragments ejected during explosive volcanic eruptions. Both are vesicular, but scoria is denser and more coarsely cellular (vesicles are larger) than most pumice (Peterson and Mason, 1983). The vesicular nature of scoria and pumice results in lower density and higher porosity than most rock types. These properties result in commercial use as lightweight aggregates, insulators, absorbents, and abrasives (Geitgey, 1994; Harden and Bates, 1984). Scoria typically has a higher crushing strength than pumice and is more desirable for certain aggregate uses.

Scoria--Scoria is red, black, or gray, and of basaltic composition (50–60 percent SiO_2). Most scoria fragments occur as poorly consolidated, poorly to to well-sorted and stratified cones or mounds (Geitgey, 1994; Peterson and Mason, 1983; Osburn, 1979, 1982; Cima, 1978). Ejected material ranges in size from volcanic ash or cinder and scoria with particle diameters ranging to 100 mm to smooth-sided volcanic bombs and angular blocks with diameters in excess of 100 mm. Most volcanic cinder cones contain approximately 75 percent scoria (Cima, 1978; Osburn, 1979, 1982). Scoria is quarried from open pits by digging with tractors and rippers, and is stockpiled, crushed, and screened (Osburn, 1982).

The morphology of the cinder cone or volcano is important in determining the economic viability of potential scoria deposits. The aspect ratio (Osburn, 1979, 1982) is the ratio of the height of the cinder cone or volcano to its average basal diameter. Most economic deposits occur

within cones with aspect ratios between 0.1 and 0.2 (Osburn, 1982). Cones with lower aspect ratios (<0.1) tend to have thick, lava flows undesirable for mining; those with higher aspect ratios (>0.2) tend to consist of large amounts of agglutinate (scoria blocks welded to dense lava blocks) and approach spatter cones. Agglutinate deposits require blasting, increasing production costs. Economic considerations of a scoria deposit include its color, grain size, sorting, density, and consolidation.

Currently scoria is used in the manufacture of cinder block and concrete. Some scoria is also used as a decorative stone for landscaping. Use in landscaping depends on select size and color (reddish-brown is most popular). Cinders are used on highways during winter storms to improve traction and on steep slopes to control erosion. In the 1950s, scoria was used as railroad ballast and road aggregate. Other applications include uses in the roofing industry.

Scoria is typically a low-cost commodity that is sold locally. In the Mimbres Resource area, most scoria is utilized in the Las Cruces and El Paso areas. In Doña Ana and Luna Counties, scoria deposits are found in the Potrillo Mountains and adjacent areas, encompassing an area of more than 200 mi^2 and about 150 cinder cones (Seager and Mack, in press)(**figure 7-11**). Some cones have been quarried, but total production is unknown. Production from 1975–1988 totaled $1.75 million (**table 7-5**). In the West Potrillo Mountains, Mt. Riley, and Aden Lava Flow Wilderness Study Areas, Kilburn and others (1988) estimate an inferred resource of at least 400 million yd^3. An additional scoria deposit is found at Black Mountain, northwest of Deming. There is no known production from this deposit.

Scoria resources in Doña Ana and Luna Counties are large and should be sufficient to meet local demand in the near future (Austin and others, 1982; Osburn, 1982). Much of the Potrillo Mountains are within Wilderness area boundaries; however, active mining operations are located outside of restricted areas.

Pumice--Pumice is a common constituent of many rhyolitic ash-flow tuffs (or ignimbrites) (Austin, 1994; McIntosh and others, 1991; Elston, 1989; Richter and others, 1983). It is white, gray, pale yellow, pink, or brown, and vesicular. Pumice is dacitic to rhyolitic in composition (60–70 percent SiO_2)(Greitgey, 1994; Harben and Bates, 1984). Finer pumice fragments (<2 mm) are called pumicite or volcanic ash. Economic considerations of pumice include grain size, density, hardness, moisture content, and composition.

In 1993, half of the total U.S. production of pumice was used in concrete admixtures, decorative blocks, laundries (stone washing), and building blocks (Presley, 1994). Pumice is also used in abrasives, millstones, abrasive wheels, aggregates, hand soap, scouring components (including toothpaste), insulation, pesticide and herbicide carriers, roofing granules, landscaping,

filter media, and in agricultural uses (Presley, 1994; Geitgey, 1994; Austin, 1994; Hoffer, in press; Harben and Bates, 1984; Clippinger and Gay, 1947). Pumice is quarried and screened (Austin, 1994). For applications in stone washing, pumice blocks over 1.9 cm dimension are necessary, and the material must have a composition that is low in iron and other chemically active impurities (Hoffer, in pres; Geitgey, 1994). Lightness of color is desirable for the manufacture of decorative blocks. A high degree of porosity, large surface area, and low chemical reactivity is required for use as an absorbent and chemical carrier. Block pumice is currently in demand for stone- and acid-washing of denium.

In the Mimbres Resource Area, economic concentrations of pumice are rare (**figure 7-12**). Development of pumice deposits has occurred only in the Pyramid Mountains in Hidalgo County. Four deposits occur in Grant County, and may have been produced for use as aggregate, but specific production data is speculative (and presumed to be low). The resource potential for block pumice in the Mimbres Resource Area is low. Only a few localities with sufficient quantities for aggregate production are known. Large distance to manufacturers and other markets, poor quality, and unknown tonnage probably will limit pumice production in the study area in the forseeable future, except for minor local use as road aggregate and landscaping.

ZEOLITES IN TERTIARY VOLCANICLASTIC ROCKS

by Richard A. Sheppard

Zeolites belong to a group of naturally occurring minerals known as framework silicates, which also include feldspars and feldspathoids. The name of this remarkable group of minerals was given in 1756 by Baron Cronstedt, a Swedish mineralogist. The name is derived from the Greek *zein*, to boil, and *lithos*, stone, in allusion to the intumescence of most zeolites with a borax bead. Specifically, zeolites are crystalline hydrated aluminosilicates of the alkali and alkaline-earth elements. They have an infinitely extended framework structure that encloses interconnected cavities occupied by the relatively large exchangeable cations and water molecules. The fundamental building block of the zeolites is a tetrahedron of four oxygen atoms surrounding a relatively small silicon or aluminum atom. The framework structure of zeolites consists of SiO_4 and AlO_4 tetrahedra such that each oxygen is shared between two tetrahedra. Thus, the atomic ratio, O:(Al+Si), is equal to 2. Because aluminum has one less positive charge than silicon, the framework has a net negative charge and is balanced by the exchangeable cations. These cations are chiefly monovalent sodium and potassium and divalent calcium and magnesium, but divalent barium and strontium are essential constituents of some natural zeolites.

Since zeolites were discovered more than two centuries ago, nearly 50 distinct species have been recognized. Numerous zeolites have also been synthesized, but most of these have no natural

counterparts. Zeolites occur in rocks that are diverse in lithology and age, and they have formed in many different geological environments. The common and perhaps best known occurrences are in the cavities and fractures of igneous rocks, particularly basaltic rocks (Tschernich, 1992). Most of the large, attractive zeolite specimens in museum collections have been obtained from igneous rocks. In recent years, zeolites have been recognized as important rock-forming constituents in low-grade metamorphic rocks and in various sedimentary rocks (Hay, 1966; Mumpton, 1993). The zeolites in sedimentary rocks are very finely crystalline and do not appeal to mineral collectors, but deposits of this type are voluminous and have economic potential for many industrial, agricultural, and environmental applications (Clifton, 1987).

Zeolites are among the common authigenic silicate minerals that occur in sedimentary rocks. Since the discovery by Murray and Renard (1891) of phillipsite in deep-sea deposits, zeolites have been recognized from many different sedimentary rocks and depositional environments. Although about 20 different zeolites have been reported from sedimentary rocks throughout the world (Sheppard, 1973), only analcime, chabazite, clinoptilolite, erionite, mordenite, and phillipsite make up the major part of zeolitic rocks of southwestern New Mexico. Clinoptilolite is by far the most commonly reported zeolite.

Zeolites typically occur in Cenozoic continental tuffs and tuffaceous sedimentary rocks that originally contained silicic, vitric ash. Zeolitic tuffs generally are white or pastel shades of green, yellow, orange, pink, or brown, relatively hard, and dull or earthy. The zeolite-rich rocks commonly break with a blocky or conchoidal fracture. Unlike fresh (unaltered) volcanic ash, the zeolitic tuffs are resistant and ledge forming, particularly in arid areas. Original textures and sedimentary structures, such as ripple marks, are generally preserved in the zeolitic rocks. Many zeolitic sedimentary rocks consist of two or more zeolites as well as authigenic clay minerals, silica minerals, or feldspars, and relict glass and crystal and rock fragments.

Most zeolites in sedimentary deposits formed after burial of the enclosing sediments by the reaction of aluminosilicate materials with the interstitial water, which may have originated as either meteoric water (open-system type) (Hay and Sheppard, 1993) or connate water of an alkaline, saline lake (closed-system type) (Surdam and Sheppard, 1978). The interstitial water responsible for the alteration also may have originated from hydrothermal solutions (Utada and Vine, 1984). Silicic volcanic glass is the aluminosilicate material that most commonly served as the precursor for the zeolites, although materials such as clay minerals, feldspars, feldspathoids, and gels also have reacted locally to form zeolites. Hay (1966) showed that the formation of authigenic zeolites and associated silicate minerals can be correlated with the following factors: (1) composition, grain

size, permeability, and age of the host rocks, (2) composition of the pore water, including pH, salinity, and proportion of dissolved ions, and (3) depth of burial of the host rocks.

Properties of zeolites

Most natural zeolites show considerable ranges in chemical composition, including ranges in the water content, the cation content, and the Si:Al ratio. Summaries of their composition have been given by Hay (1966), Utada (1970), Sheppard (1971), and Gottardi and Galli (1985). The formulas and ranges in simplified form are given in **table 7-6**. The zeolites in sedimentary rocks are generally alkalic and more siliceous than their counterparts that occur in mafic igneous rocks. The indices of refraction of zeolites are low for silicate minerals and are generally in the range of 1.46-1.52. The specific gravity is notably low as a consequence of the porous structure of the zeolites and is generally 2.0-2.3. Hardness is about 3.5-5.5.

The wide diversity of applications and potential applications of natural zeolites are due to a unique set of properties, some of which were recognized more than a century ago. These properties include reversible dehydration, cation exchange, adsorption, and thermal and acid stability. These properties for both natural and synthetic zeolites were discussed in detail by Breck (1974) and will not be further reviewed here. When zeolites are dehydrated, the remaining crystalline solid is characterized by molecular-size voids that have a large internal surface area. Once so cleared of water, the cavities are capable of adsorbing other molecules that are small enough to pass through the apertures that connect the voids. This ability to select one or more components from a gas or liquid mixture to the exclusion of the others is known as molecular sieving. Thus, natural zeolites and their synthetic counterparts are commonly termed molecular sieves.

Zeolites in sedimentary deposits are finely crystalline, commonly in the range of 1-60 μm. Because of their fine crystallinity and similar optical properties, these zeolites were geneally overlooked until the widespread use of X-ray powder diffraction techniques in the late 1950s.

X-ray powder diffraction analysis of bulk samples is now the technique generally used for identification of the zeolites. This method also permits a semiquantitative estimate of the abundance of zeolites and associated minerals in the sample.

Scanning electron microscopy has been applied with success to the study of finely crystalline zeolites. This method is especially useful for the determination of the size and shape of the crystals in the bulk rock and for the study of the paragenesis of the diagenetic minerals. Because of the characteristic morphology of many zeolites in sedimentary deposits, the electron microscope also supplements the use of the X-ray diffractometer for identification.

Utilization of natural zeolites

The commercial utilization of natural zeolites in the United States is in its infancy, but the seemingly useful physical and chemical properties of zeolites, the high grade of many deposits, and the relatively low cost of mining suggest greatly increased utilization in the near future. Synthetic zeolites have been used for about 40 years in diverse industrial applications, including applications as catalyst supports, selective sorbents, and desiccants (Breck, 1974). The utilization and potential utilization of natural zeolites have recently been discussed in Pond and Mumpton (1984), Kallo and Sherry (1988), and Mumpton (1993) and will be only briefly summarized here.

The earliest uses of zeolites and zeolitic tuff throughout the world were as pozzolanic (consisting of powdered volcanic rock) raw material in cement and as lightweight building stone. These early uses were, of course, made without knowing that the materials consisted chiefly of zeolites. Demand for zeolitic tuff for these uses in the United States is now almost nil. In central Europe, however, zeolitic tuff continues to be used in pozzolanic cement (cement that has a silicic, volcanic component) as it has been used for many centuries. Clinoptilolite is the most common constituent of tuff used as pozzolan, but analcime, chabazite, and phillipsite are major constituents in some. Zeolitic tuff is also quarried for building stone in Mexico, Japan, and many countries of central Europe. Other potential uses of zeolitic tuff, made possible by the gross properties of the rock rather than the chemical or physical properties of the zeolite constituents, include fillers for paper and the production of lightweight aggregates.

Applications of zeolites in cation-exchange and adsorption processes promise to utilize large tonnages of natural zeolites in the near future. In recent years, natural zeolites have found increasing applications in the general field of agriculture, in the recovery and utilization of energy resources, and in a variety of pollution-abatement processes (International Committee on Natural Zeolites, 1993). Agricultural applications of clinoptilolite (Pond and Mumpton, 1984) include soil amendments; carriers for pesticides, fungicides, and herbicides; feed supplements added to the rations of pigs, ruminants, and chickens to improve the health of the animals and to increase the feed-conversion values; control of the moisture content and malodor of animal manure; and removal of toxic ammonium ions from recirculating fish-culture systems. Recent experiments and pot tests suggest that controlled-release fertilizers can be prepared from a mixture of phosphate rock and NH_{4^+}-saturated clinoptilolite (Lai and Eberl, 1986).

Energy applications include the use of chabazite to treat sour natural gas; the use of clinoptilolite and mordenite to remove SO_2 and other noxious emissions from stack gases of oil- and coal-burning power plants; use of chabazite and clinoptilolite for solar energy applications in both heating and refrigeration; use of mordenite to produce oxygen-enriched streams from air that

would be suitable for coal gasification; and use of erionite and clinoptilolite as catalysts or catalyst supports in petroleum cracking.

Applications of natural zeolites in pollution-abatement processes include the use of clinoptilolite for the removal of NH_{4^+} in tertiary sewage treatment; the use of clinoptilolite in water-filter media for relatively small drinking water systems; the use of clinoptilolite to remove radioactive cesium from nuclear wastewater or to immobilize certain radionuclides in contaminated soils; and the use of clinoptilolite, chabazite, or phillipsite to remove certain heavy metals from wastewater. Recent research indicates that clinoptilolite, in particular, is effective for the remediation of acid-rock drainages by the removal of cadmium, copper, lead, and zinc (Zamzow and others, 1990; Desborough, 1993).

OCCURRENCES OF ZEOLITES IN SEDIMENTARY DEPOSITS OF SOUTHWESTERN NEW MEXICO

Zeolites in tuffaceous sedimentary deposits of southwestern New Mexico occur chiefly in lacustrine and fluviatile environments or in tuffs that were air laid on the land surface. Although zeolites are known from several localities in Tertiary volcaniclastic rocks across the northern part of the Mimbres Resource Area (**figure 7-13**), data on most of the deposits are sparse, except for those zeolites near Buckhorn, Grant County. Therefore, the information given herein is, unfortunately, uneven. Zeolites have been recognized from Grant, Luna, and Doña Ana Counties but apparently not from Hidalgo County.

Buckhorn, Grant County

Zeolites are widespread and locally abundant in tuffaceous rocks in a lacustrine facies of Pliocene(?) age in the upper part of the Gila Conglomerate near Buckhorn, Grant County. This part of the Gila Conglomerate was deposited in a major northwest-trending structural feature known as the Mangas trench (Trauger, 1972). The lacustrine facies of the Gila Conglomerate has been dissected by Duck Creek (a tributary of the Gila River) and its tributaries, forming badlands. The zeolitic tuffs and tuffaceous sediments dip very gently eastward and are unconformably overlain by unconsolidated Quaternary gravels. These gravels commonly drape the slopes of the badlands and conceal much of the lacustrine rocks.

Zeolites were first discovered in the Buckhorn area in 1962 by T. H. Eyde during a zeolite exploration program for Union Carbide Corporation (Mumpton, 1984). Subsequent studies (Olander, 1979; Eyde, 1982; Bowie and others, 1987; Sheppard and Gude, 1987; Gude and Sheppard, 1988) have shown that zeolitic tuffs crop out over an area of about 11 km^2 southeast of Buckhorn and chiefly southwest of Duck Creek, from SE1/4 sec. 4, T.15 S., R. 18 W. southeastward to NW1/4 sec. 22 and NW1/4 sec. 24, T. 15 S., R. 18 W. The lacustrine rocks

southeast of Buckhorn are at least 50 m thick and consist chiefly of brown, gray, green, and red mudstone and siltstone that locally contain interbeds of limestone, chert, and tuff. Interbeds of silicic tuff are generally zeolitized and are 10 cm to 2.75 m thick. Most of the fine-grained clastic rocks of the lacustrine unit are tuffaceous and commonly zeolitic.

A conspicuous, resistant, 0.45- to 2.75-m thick tuff in the lower part of the lacustrine sequence is known as the marker tuff (Gude and Sheppard, 1988) and is the principal zeolitic unit. The rhyolitic marker tuff is multiple bedded, thin to thick bedded, and locally cross bedded (**figure 7-14**). Although some parts of the tuff are white, most of the tuff is a light shade of gray, yellow, or brown. Nowhere in the Buckhorn area is the marker tuff free of diagenetic alteration, but parts of the tuff locally contain as much as 50 percent vitric material. Pyrogenic crystals in the tuff include sodic plagioclase, quartz, biotite, and hornblende.

Gude and Sheppard (1988) showed that three lateral diagenetic zeolite zones are recognizable in the marker tuff. From northwest to southeast, the zones are characterized by chabazite, clinoptilolite, and then analcime. The chabazite zone contains glass and minor clinoptilolite or erionite in addition to the diagnostic chabazite which makes up a trace to 90 percent of the tuff. The clinoptilolite zone locally contains trace to minor amounts of erionite in addition to the diagnostic clinoptilolite, which makes up as much as 95 percent of the tuff, but lacks glass or analcime. The analcime zone contains mainly clinoptilolite and minor amounts of erionite in addition to the diagnostic analcime, but glass is absent from this zone. Mordenite locally is a minor constituent of the marker tuff. In addition to the ubiquitous authigenic zeolites, the marker tuff locally contains authigenic smectite and, more rarely, opal-CT, quartz, calcite, fluorite, and gypsum.

The zeolites in the marker tuff are generally very finely crystalline (less than 15 μm), and use of scanning electron microscopy is necessary to determine the crystal size, morphology, and grain relationships. Clinoptilolite typically occurs as well-formed tabular crystals that are 2-20 μm long. Locally the clinoptilolite occurs in fan-like or radial aggregates (**figure 7-15**). Chabazite occurs as minute rhombohedra that are less than 0.3 μm to 6 μm in size (**figure 7-16**). Erionite commonly occurs as bundles of prismatic or acicular crystals that are 6-20 μm long. The analcime occurs as trapezohedra that are 6-45 μm in diameter. The paragenetic sequence (from early to late) as determined by Gude and Sheppard (1988) is smectite, chabazite, clinoptilolite, erionite, and then analcime.

Chemical analyses of nearly monomineralic bulk samples of the zeolitic marker tuff are given in **table 7-7** (Sheppard and Gude, 1987). The analysis of the chabazite-rich tuff shows that the chabazite is a calcic, siliceous variety. Although Olander (1979) showed that the clinoptilolite

in the marker tuff near Buckhorn is variable in composition, the analysis of clinoptilolite-rich tuff indicates a calcic variety. This analyzed sample of clinoptilolite-rich tuff was collected from a small pit (NW1/4NW1/4 sec. 10, T. 15 S., R. 18 W.) excavated by Double Eagle Petroleum and Mining Company (Casper, Wyoming). Additional chemical and physical properties of the clinoptilolite-rich tuff from this same pit have been given by Sheppard and Gude (1982), Pond and Yen (1984), Zamzow and others (1990), Desborough (1993), and Schultze and Zamzow (1993).

The zeolites and associated silicate minerals in the marker tuff and associated tuffaceous lacustrine rocks seem to have formed during early diagenesis by reaction of silicic glass with pore waters of various compositions (Sheppard and Gude, 1987). Differences in pH and salinity of the pore waters were inherited from water that was trapped in the tuffs during deposition in the ancient lake (closed-system type of alteration). The pore water probably ranged from dilute and nearly neutral in nearshore and inlet parts of the lake to saline, alkaline brine having a pH of 9 or greater in the central part of the lake.

The tonnage of zeolitic marker tuff in the Gila Conglomerate near Buckhorn is conservatively estimated at 5 million short tons on the basis of the known distribution of the tuff and an average thickness of 1.5 m. Clinoptilolite is the most abundant zeolite in the marker tuff and, although nearly monomineralic tuff has been recognized, much of the tuff contains one or more additional zeolites as well as other impurities. Although small pits have been excavated in clinoptilolite-rich marker tuff by Double Eagle Petroleum and Mining Company (Casper, Wyoming) and Zeotech Corporation (Albuquerque, New Mexico), only small shipments of the zeolitic tuff were made for water-treatment and agricultural uses.

Lacustrine mudstones in the Gila Conglomerate northeast of Duck Creek near Buckhorn commonly are zeolitic. These reddish brown, brownish gray, and greenish gray mudstones probably are stratigraphically higher than the marker tuff and crop out about 3.7 km northwest of Buckhorn (NW1/4NW1/4 sec. 29, T. 14 S., R. 18 W.) and about 2.7 km east of Buckhorn (E1/2 sec. 34 and W1/2 sec. 35, T. 14 S., R. 18 W.). Analcime or mordenite or both commonly make up 20-40 percent of the mudstone and suggest an original tuffaceous component. A light gray, mordenitic, 40-cm thick, fluorite-bearing tuff also has been recognized at the locality about 2.7 km east of Buckhorn (Sheppard and Mumpton, 1984).

Gila, Grant County

During geologic mapping of the Cliff quadrangle, Finnell (1987) recognized a zeolite-bearing vitric tuff in the Gila Conglomerate about 4.5 km southeast of Gila (SW1/4 sec. 12, T. 16 S., R. 17 W.). The gray tuff is about 55 cm thick and contains less than 30 percent chabazite, erionite, and phillipsite. Additional information about this zeolite occurrence is unavailable. Other

altered tuffs crop out still farther southeast, but zeolites were not reported. Correlation of these tuffs with those near Buckhorn was not possible.

Bayard, Grant County

Clinoptilolite has been reported in bluish-green tuff beds that are intercalated in brown sandstone in the upper part of the Oligocene Sugarlump Tuff an unspecified distance southeast of Bayard (Jones and others, 1967, p. 104). There is no additional information available on the grade, distribution, properties, or genesis of the clinoptilolite from this locality. Jones and others (1967) showed that the Sugarlump Tuff is as much as about 244 m thick in a band across the southern part of the Santa Rita quadrangle, mostly south and east of Bayard. These authors reported that some tuffs in the formation are partly or completely altered to montmorillonite.

Dwyer (Faywood Post Office), Grant County

Zeolites have not been reported from the Oligocene tuffaceous rocks near Dwyer, but a recent reconnaissance by the author (R.A. Sheppard, unpub. data, 1993) suggests widespread zeolitization. Zeolitic tuffaceous rocks were recognized along State Route 61, west of the Mimbres River, from about 6.3 km northeast of Dwyer (SE1/4SE1/4 sec. 2, T. 19 S., R. 10 W.) to about 5.7 km southwest of Dwyer (NW1/4SE1/4 sec. 6, T. 20 S., R. 11 W.), extending into northern Luna County. These tuffaceous rocks were mapped by Elston (1957) as the Sugarlump Tuff and the Rubio Peak Formation.

The zeolitic tuffaceous rocks are white, light pink, and green and include well-bedded, reworked tuffs (**figure 7-17**) as well as massive, nonwelded lapilli tuffs. All of these tuffaceous rocks contain variable amounts of obvious, angular pumice, lithic, and crystal fragments. Except for probable andesitic flows and welded, silicic ash flows, much of the volcaniclastic rocks in this area contain at least a trace of diagenetic clinoptilolite (**figure 7-18**). Sampled zeolitic tuffaceous rocks range in thickness from about 2 m to at least 30 m. X-ray diffractometer analyses of sampled tuffs indicate that a green tuff unit in the Sugarlump Tuff in the SE1/4SE1/4 sec. 32, T. 20 S., R. 11 W. contains as much as 80 percent clinoptilolite. In addition to clinoptilolite, the tuffaceous rocks locally contain diagenetic chabazite, mordenite, smectite, and quartz. The finely crystalline quartz makes up 10-30 percent of the rocks and is responsible for their characteristic hardness.

Much additional work needs to be done in the Dwyer area before the zeolite potential can be evaluated. A regional investigation should determine the distribution of clinoptilolite and coexisting authigenic minerals, determine the pattern of alteration, and evaluate the chemical and physical properties of the zeolitic rocks. Without further data, this zeolite deposit is suspected to be of the open-system type. Inasmuch as Elston (1957) mapped a broad band of tuffaceous rocks

in the western half of the Dwyer quadrangle (chiefly west of the Mimbres River), a potentially vast tonnage of clinoptilolite-bearing rock may exist in Grant and Luna Counties.

Foster Canyon, Doña Ana County

Zeolites, chiefly clinoptilolite, have been reported in volcaniclastic rocks in the upper part of the Oligocene Bell Top Formation in the Foster Canyon area of Cedar Hills, about 28 km northwest of Las Cruces (Bowie and others, 1987). Zeolites were first recognized in the eastern part of T. 21 S., R. 2 W. and the western part of T. 21 S., R. 1 W. by S.L. Peterson in 1977 (S.L. Peterson, oral commun., 1994). This zeolite locality is in tuffaceous rocks that were deposited in the Goodsight-Cedar Hills volcano-tectonic depression, an asymmetric basin about 80 km (north-south) long and 38 km wide (Seager, 1973). Part of the nearly 550 m of basin fill is the Oligocene Bell Top Formation, chiefly epiclastic, volcaniclastic strata derived partly from the marginal raised rim. The Cedar Hills are along the eastern margin of the depression.

Bowie and others (1987) summarized the available data on the zeolitic volcaniclastic rocks of the Foster Canyon area, and the following information is chiefly from their report. Clinoptilolite occurs extensively throughout the upper tuffaceous sedimentary member of the Bell Top Formation, as much as about 240 m of white to brownish-pink reworked air-fall tuff, breccia, and pebbly sandstone. From 1977 to 1985, Zeotech Corporation (Albuquerque, New Mexico) augered more than 300 holes (3-6 m deep) and studied the zeolitic tuffs on their claims mainly in the NW1/4 sec. 14, T. 21 S., R. 2 W. The tuffaceous rocks contain as much as 60 percent clinoptilolite as well as authigenic opal-CT and smectite and variable amounts of crystal and lithic fragments and unaltered silicic glass. Trace to major amounts of chabazite locally coexist with the clinoptilolite. Siliceous zones locally consist mainly of opal-CT and crosscut the zeolitic tuff. The Zeotech Corporation blocked out 200,000-300,000 short tons of zeolitic tuff that averaged 50 percent clinoptilolite; however, production was not initiated, and the claims were dropped in 1985 (Schmidt, 1987).

Bowie and others (1987) supported a hydrothermal origin for at least some of the zeolites, but the genesis of this deposit needs additional study. The clinoptilolite occurs as subhedral to euhedral laths that are commonly 20-30 μm long. Scanning electron microscopy showed that smectite crystallized both before and after the clinoptilolite (Bowie and others, 1987).

RECOGNITION OF UNDISCOVERED ZEOLITE DEPOSITS

Future exploration for potentially commercial zeolite deposits in the Mimbres Resource Area should concentrate on those areas underlain by Cenozoic volcaniclastic rocks that originally contained abundant silicic glass. Zeolites can form from a variety of aluminosilicate materials during diagenesis, providing the interstitial water has a relatively high pH and high concentration

of alkalis. The high-grade zeolite deposits, however, formed from silicic, vitric ash that lacked crystal and lithic fragments.

Prospecting for bedded zeolite deposits is difficult because the zeolites are finely crystalline and resemble bedded diatomite, feldspar, or bentonite in the field. Zeolitic tuffs generally have an earthy luster and are resistant. Although some zeolitic tuffs are pastel shades of yellow, brown, red, or green, many are white or light gray. X-ray powder diffraction analysis of bulk samples is the technique generally used for identification of the zeolites and associated minerals in sedimentary rocks. This method also permits a semiquantitative estimate of the abundance of mineral phases in the samples. Tuffaceous strata are sampled, and then the samples are brought to the laboratory for examination by X-ray diffraction. Fresh (unaltered) tuff is generally distinguishable from altered tuff in the field, so only the altered parts of the tuffaceous rocks are sampled in both vertical and lateral directions. Once zeolites have been identified by X-ray diffraction, an additional sampling is commonly necessary to ascertain the distribution and abundance of the zeolites and coexisting authigenic minerals.

Potential targets for undiscovered zeolite deposits in the Mimbres Resource Area include: (1) the Oligocene Sugarlump Tuff and equivalent strata in a band between Bayard-Hurley and the Mimbres River, (2) Tertiary rhyolitic tuffs in the Animas Mountains, Pyramid Mountains, Pierce Peak, and Cedar Mountain Range in the southwestern part of the area, and (3) lacustrine facies of the Gila Conglomerate and equivalent strata. Air-fall, silicic tuffs that were deposited in water are particularly good targets, but even land-laid, silicic, nonwelded ash-flow tuffs should not be overlooked. Most of the four-county area was shown by Schmidt (1987, p. 14) to be favorable for potential zeolite occurrences.

ENERGY RESOURCES

GEOTHERMAL RESOURCES

by W.A. Duffield and Susan S. Priest

General Information

Geothermal energy is the natural heat of the Earth, and thus geothermal resource assessment is the estimation of what fraction of the Earth's heat might be extracted economically now or in the foreseeable future. Though heat is rather intangible compared to such resources as minerals and petroleum, geothermal energy can still be classified into deposits that define a broad spectrum of tonnage (volume) and grade (base temperature). A given deposit is a resource, in the restricted sense of this word, only if an appropriate combination of porosity, permeability, temperature and depth represents an economically developable target under current or reasonably forseeable

conditions. Of the several geothermal environments in the upper crust, only hydrothermal-convection systems are resources or potential resources in today's marketplace.

Geothermal environments are commonly classified in terms of temperature and available H_2O (**figure 7-19**). Magma is the highest grade geothermal deposit in terms of temperature but is so hot and chemically corrosive that common materials are destroyed when inserted into the silicate melt. Rock that is hot but does not contain available H_2O is not a resource simply for lack of water and/or permeability to carry thermal energy to the Earth's surface where it can be put to work. Both the magma and hot-dry-rock environments have been subjects of research during the past couple of decades. The feasibility that thermal energy can be extracted from each of these environments has been demonstrated, but neither environment is economic in the current or near-term market place (Duffield and others, 1994). In contrast, water-saturated permeable rocks at all temperatures in the upper crust are geothermal resources or potential resources.

Hydrothermal systems hotter than about 200^{o}C are capable of producing sufficient high-pressure steam to drive a turbine generator. Such systems currently power about 6,000 megawatts of electrical capacity (equivalent to about 6 times the capacity installed at Glen Canyon Dam) worldwide. Between roughly 200^{o}C and 100^{o}C, hydrothermal systems are not capable of powering steam-driven turbine generators, yet their thermal energy can boil a second fluid (e.g., isobutane) whose vapor can power a turbine generator. These so-called binary systems considerably broaden the temperature range over which geothermal deposits can be used to generate electricity. A recently constructed isobutane-based binary system at Long Valley, California, has an installed generating capacity of 45 megawatts electric, enough to satisfy the electical demands of an average United States city of about 45,000 population.

Geothermal waters too cool to power even a binary electrical plant can, nonetheless, be put to many direct uses, from agricultural applications to space heating to product drying to balneology. Other possible direct uses include all processes that require relatively low-temperture thermal energy. Probably all known geothermal resources in the Mimbres study area are in the direct-use temperature range.

Finally, a recently introduced and rapidly growing direct application of geothermal energy requires neither anomalous temperature nor hydrothermal water. A heating/cooling system (called a geothermal heat pump) for homes and larger buildings simply takes advantage of the fact that rock and soil are excellent thermal insulators. In this application, piping is buried a few meters underground, where temperature fluctuates little with the changing seasons. Then, by circulating water or some other fluid through this piping using a standard heat pump, thermal energy is

extracted from the ground during the coldest times of the year and deposited in the ground during the hottest times. Together, the heat pump and Earth's thermal energy form a small, effective and commercially viable heating and cooling system. Efficiency is notably greater than that of a "traditional" heating/cooling system, which exchanges thermal energy with the ambient atmosphere. Recent installations of geothermal heat pumps are so numerous that accurate current statistics are elusive. Estimates range from 100,000 to 400,000 such systems now in use in the United States.

Resource Assessment:

The U.S. Geological Survey completed three national geothermal-resource assessments during the past two decades (White and Williams, 1975; Muffler, 1979; Reed, 1983). These are a primary source of resource information for evaluation of the Mimbres study area. Agencies of state governments, especially in the western part of the United States, have also assessed their geothermal resources during the past decade or so (e.g., New Mexico State University, 1980; Morgan and others, 1983; Callender and others, 1983). These state publications supplement the national data base.

Geothermal resources presently of greatest economic value are those capable of being developed to generate electricity. Electrical projects represent relatively large energy-extraction rates and, once converted, this energy is easily transported to distant markets. Most geothermal resources of electrical-grade temperatures are directly associated with geologically young, if not active, silicic volcanism. Silicic compositions imply a mid or upper crustal magma reservoir where basalt fractionated and/or partly melted preexisting crustal rocks. Once formed, a crustal magma reservoir is a potent heat source for driving hydrothermal-convection systems.

Within the Mimbres study area, hydrothermal systems whose temperatures are accurately known are too cool for generating electricity (**figure 7-20**). The study area has no active volcanoes, although Quaternary basaltic volcanic rocks are locally abundant in the West Potrillo Mountains. However, magma that fed these eruptions likely rose so rapidly from source regions in the upper mantle that magma reservoirs were not established in the crust. Evidence of such rapid rise is recorded as rather primitive basaltic compositions of the lavas (indicative of little or no interaction with the crust) and as eruptive products with locally abundant high-density xenoliths that could be suspsended in and carried upward only by magma that rose rapidly to sites of eruption.

Some potential for marginally electrical-grade, undiscovered hydrothermal systems is suggested by subsurface temperatures estimated from the types and amounts of chemical constituents dissolved in waters collected at hot springs or from shallow wells (Morgan and others, 1983, several temperatures reported between about 100 and 180^{o}C). However, such calculated

temperatures must be carefully evaluated with regard to the lithologic types and compositions of rocks with which the fluids interacted to obtain the dissolved constituents. Moreover, calculated temperatures are suspect when they differ greatly for different chemical geothermometers applied to the same sample, as is the general case with the results reported by Morgan and others (1983). Finally, drilling is the only direct way to confirm subsurface temperature, and with the sole exception of the Lightening Dock (Animas) area, temperatures in wells are all below the electrical-grade range.

Though the potential for electrical-grade resources seems very low, the relatively high heat flow which is characteristic of the Mimbres study area suggests the possibility of many undiscovered, lower-temerature geothermal resources. The entire study area has heat flow greater than the world crustal average of about 40 milliwatts per square meter (mW/m2), and nearly half of the study area has heat flow three-or-more-times the world average (**figure 7-21**). Thus, geothermal resources appropriate for non-electric applications could be widespread at easily drillable depths. Temperature gradients in the range of 40-50^{o}C/Km are common in the study area, and standard drilling technologies can easily reach depths of 2-3 kilometers. However, risk of failure to discover a resource through drilling, especially when the resource is anticipated to be of non-electrical grade, can a formidable financial barrier to much geothermal exploration.

If non-electrical resources are fairly widespread, they likely are mostly in sedimentary basins, which are the natural regional sumps for groundwater flow. Thus, an accurate assessment of geothermal resources in the study area is limited by our understanding of subsurface hydrology, both locally and regionally. Hydrothermal systems potentially of resource caliber within basin-fill sediments and permeable fault zones are hidden because the water table seldom intersects the Earth's surface in such an arid climate.

PERMISSIVE TRACTS: On the basis of heat flow alone, the entire study area can be classified as a permissive tract. As explained above, any undiscovered resources are anticipated to be too low temperature for generation of electricity. Nonetheless, a widespread low-temperature resource may be appropriate for a variety of direct uses. In general, areas of higher heat flow might be expected to yield higher temperatures at a given depth, relative to areas of lower heat flow. However, the temperature/depth relation is also dependent on rock type and associated thermal conductivity. Of equal, or even greater importance, is the identification of permeable aquifers. Even high temperature is of no practical use if water is not present to carry thermal energy to the Earth's surface where it can be put to use.

FAVORABLE AND PROSPECTIVE TRACTS: A 10-20 kilometer wide corridor along the Rio Grande, the Animas Valley, the Mangas Graben and the Gila Hot Springs area are

lumped as favorable/prospective tracts. These are the only areas of current geothermal-resource development and use. With the single exception of a temperature slightly above boiling at the bottom of a well in the Animas Valley, all of the developed resources are definitely restricted to non-electrical applications. Broadly speaking, common geologic characteristics are relatively thick accumulations of sediments in down-faulted troughs. Resources known from drilling are more abundant than those with natural surface manifestations. Of some interest is the fact that the highest known temperature (Animas Valley) was accidentally discovered from drilling for purposes other than geothermal exploration. Undrilled areas within these tracts are relatively attractive targets for future exploration and discoveries.

URANIUM OCCURRENCES

Virginia T. McLemore, NMBMMR

Introduction

Uranium deposits are found in four types of deposits as defined by McLemore and Chenoweth (1989) in the Mimbres Resource Area (**table 1-6**): 1) epithermal veins, 2) skarns, 3) pegmatites, and 4) surficial deposits. These deposits range in age from Proterozoic through Quaternary and are found scattered throughout the Mimbres Resource Area (**figure 7-22**). Uranium production has been minor compared to elsewhere in New Mexico (McLemore and Chenoweth, 1989) and has been restricted to four mines in the area (McLemore, 1982, 1983, 1992). Less than 1500 pounds of U_3O_8 have been produced from the Mimbres Resource Area.

Mining history

Uranium was first discovered in 1920 when torbernite was found at the Merry Widow mine in the White Signal district and the Black Hawk mine in the Black Hawk district (Hess, 1922). An unknown amount of radium was produced from the White Signal district during the 1920s from several mines. Some of this radium was used at a sanitarium at Silver City for medical purposes (Hess, 1924).

In the 1950s, intense exploration of uranium for atomic weapons and commercial power plants occurred. Government incentive programs encouraged development of small deposits of uranium. During the 1950s and 1960s, four mines in the Mimbres Resource Area produced uranium (**table 1-6**). The government programs ended in the 1960s and production and exploration for uranium in the Mimbres Resource Area ceased. The discovery and production of larger deposits in the Grants district (McLemore and Chenoweth, 1989) were more desirable targets for most companies. In the 1970s, a perceived energy shortage once again encouraged prospectors and companies to examine the Mimbres Resource Area for uranium. Although several prospects were drilled and sampled, none were developed. The decrease in demand for uranium forced most

prospectors and companies to drop their mining claims. Currently only a few mining claims are filed in the Mimbres Resource Area for uranium.

DESCRIPTION OF SELECT AREAS

Brief descriptions of uranium deposits in the Mimbres Resource Area are in **table 1-6** and described in more detail in cited references. A few of the more important uranium districts are described below. Most of the deposits are described under the appropriate mining district.

Burro Mountains

Over 100 uranium and thorium epithermal vein deposits are found in the seven districts covering the Burro Mountains: Telegraph, Black Hawk, Burro Mountains, White Signal, Malone, Gold Hill, and Bound Ranch districts. The Burro Mountains are highly mineralized and contain significant deposits of gold, silver, copper, lead, zinc, and fluorspar (North and McLemore, 1986; Richter and Lawrence, 1983; Gillerman, 1964, 1968); uranium epithermal-vein deposits are associated with some of these deposits.

Several hundred veins occur along faults in Precambrian granite in the White Signal district and most contain uranium (Gillerman, 1964; McLemore, 1983). Most of the epithermal veins have only been prospected at the surface, but a few have been developed to depths just over 61 m. Four types of veins are recognized: (1), quartz-pyrite veins; (2), quartz-specularite veins; (3), silver and silver-lead veins; and (4), turquoise veins. Uranium occurs in all four types, but the larger uranium deposits occur in the quartz-pyrite veins. The uranium-bearing veins occur at the intersection of the east-trending quartz-pyrite veins and northwest-trending diabase dikes (Gillerman, 1964, 1968). The Floyd Collins and Inez deposits are associated with diabase dikes; however, quartz-pyrite veins are also absent. The Blue Jay-Banner deposits occur within altered latite(?) dikes along a major east-trending fault (the Blue Jay fault). At the Blue Jay prospect, quartz-pyrite veins are absent; however, they are present farther to the west along the fault at the Banner prospect. In general, uraninite is present at most deposits but the dominant uranium minerals are secondary phosphates. The veins are small and irregular, but several veins can occur along a fault. The age of mineralization is uncertain, but field relationships and association with Tertiary intrusives suggests a Tertiary age.

Black Hawk mining district is known for Laramide epithermal veins containing appreciable amounts of silver, nickel, cobalt, and uranium. This unique mineral association is rare and occurs in only a few localities in the world (Gillerman, 1964). Pitchblende was first discovered in 1920 (Hess, 1922). None of the veins in this district have produced any uranium, however, considerable silver has been produced. The veins fill fractures and faults that trend northeasterly in the Precambrian granite and Tertiary Twin Peaks monzonite porphyry stock. Uraninite is the

predominant uranium mineral, although it is a minor constituent of the silver veins. The veins tend to thin at the Twin Peaks monzonite porphyry-Precambrian granite contact; although where veins occur along the margins of some of the monzonite porphyry dikes, they tend to thicken and concentrate ore minerals (Gillerman, 1964, 1968).

Uranium potential of this area is speculative. A dump sample from the Alhambra mine assayed 0.17 percent U_3O_8 and higher assays are reported (Gillerman, 1964, 1968). However, very little information on the depths of these veins is available. Drilling of this area is required to adequately assess the uranium, nickel, cobalt, and silver potential. Uranium could be recovered as a co-product of the other metals.

Uranium mineralization is associated with the Tyrone porphyry copper deposit in the Burro Mountains district. Torbernite and autunite occur in the kaolinized areas of the porphyry copper deposit (Kolessar, 1970). This copper deposit occurs in the Tertiary Tyrone quartz monzonite laccolith (Tertiary) and the underlying Precambrian Burro Mountain granite. Copper mineralization, dominantly as chalcocite, varies from a meter to 91 m in thickness and is associated with sericitic alteration. Uranium occurs in highly fractured, kaolinized areas of the Tyrone laccolith and Precambrian granite (McLemore, 1983). This hydrothermal deposit has been classified as allogenic by O'Neill and Thiede (1982) based on (1) a Precambrian granitic source, (2) low thorium-to-uranium ratios, and (3) low thorium concentrations. However, in the vicinity of the Tyrone copper mine uranium is sporadic, discontinuous, and secondary, and is not economic at the present time (Joseph Kolessar, pers. commun., 9/22/82). Uranium occurrences in the Copper Mountain area near the Tyrone porphyry (Kolessar, 1970; McLemore, 1983) are also low-grade, discontinuous, and subeconomic.

Wild Horse Mesa area is in the eastern part of the Telegraph district in the northern Burro Mountains, Grant County (**figure 7-22**). In this area, the Burro Mountain granite is unconformably overlain by the Beartooth Quartzite and Colorado Shale (Cretaceous). Although uranium has not been produced in this area, fluorite and base metals have been. Currently this area is inactive except for sporadic exploration for uranium, fluorite, and precious metals.

Uranium mineralization occurs as (1), veins along faults, shears, and fractures within Precambrian granite; (2), veins along faults between the granite and Beartooth Quartzite; (3), veins and replacements of quartzite along the unconformity between the granite and Beartooth Quartzite in the vicinity of mineralized faults; and (4), minor amounts within fluorite veins that cut the granite (McLemore, 1983). The veins are thin and discontinuous and are associated with hematization, silicification, and sericitic alteration. At least ten uranium occurrences are found in this area and numerous radiometric anomalies occur along the unconformity and major fault and shear zones.

Chemical analyses of nine samples range from 0.009 percent to 0.59 percent U_3O_8 and trace amounts of gold also occur. The highest chemical uranium values are from a fault zone between granite and quartzite at the Union Hill claims. The samples were taken near the portal of a 5.5 meter adit, which penetrates two shear zones. Additional radiometric anomalies occur along the same fault.

This area is highly fractured and faulted. Four major fault systems which trend northeast, northwest, west, and north (O'Neill and Theide, 1982; Finnell, 1987), appear to coincide with the uranium mineralization. The fluorspar veins trend northwest (Gillerman, 1964; Finnell, 1987) and are slightly radioactive. Tertiary rhyolites have intruded parts of the sequence, but are barren of mineralization. Two samples of rhyolite contain less than 5 ppm U (O'Neill and Theide, 1982).

Surficial deposits in the Lordsburg Mesa area

Geochemical and geophysical studies have delineated a large anomalous limonite area, which is interpreted as the surface expression of a chemical trap that may contain surficial uranium concentrations (also known as calcrete uranium deposits) north of Lordsburg (Raines and others, 1985). NURE (National Uranium Resource Evaluation program of the U.S. Department of Energy, McLemore and Chamberlin, 1986) ground water anomalies also suggest uranium could be present in this area (Sharp and others, 1978). Uraniferous calcretes typically occur along the axial portions of fluvial valleys in an arid climate with a seasonal rainfall (Carlisle and others, 1978). Evaporation rates are high and the limited runoff is largely confined to subsurface drainage basins. Ground waters are enriched in carbonate, uranium, and vanadium; uranium becomes concentrated in the calcretes formed just below the surface. Such deposits are shallow, but low grade. Additional exploration is required to prove these deposits occur in the Lordsburg Mesa area.

Skarn deposits in the Fremont district

Uranium was produced from skarn deposits in the Napane claims in the Fremont mining district at Sierra Rica, Hidalgo County. Copper, lead, zinc, and silver with some uranium occurs in silicified and recrystallized limestone and dolomite near Tertiary intrusives. Uranium mineralization is sporadic and discontinuous; additional exploration is required to properly assess this area (McLemore, 1983).

COAL RESOURCES

by J. David Sanchez

Wood and Bour (1988) and Kottlowski and others (1956) report unverified ocurrences of coal within Cretaceous rocks in the Mimbres Resource Area that are chronostrigraphically equivalent to coal-bearing Tertiary and Cretaceous rocks in other parts of the state. This study was

undertaken as part of the mineral and energy resource assessment of the Mimbres Resource Area to determine if any significant coal resources exist.

Previous work

Lower and Upper Cretaceous rocks in the study area are, for the most part, not coal-bearing (**figure 7-23**); however, a report by Kottlowski and others (1956) indicates that a possible one-ft coal bed existed in the Cretaceous Sarten Sandstone in the Love Ranch area, San Andres Mountains, Doña Ana County, north of the town of Organ in the WSMR. This outcrop was visited as part of this study, and no coal was seen in the prospect pit. Hyde (1984) measured the Sarten Sandstone in the San Andres Mountains and reported the occurrence of a 1.5 m black shale. A map by Wood and Bour (1988) indicates that four unnamed coal fields exist in the southwestern part of the State that are located in or near the Big Hatchet, Little Hatchet, Alamo Hueco, and northern Animas Mountains. Field investigations of these reproted unnamed coal fields, along with interviews with P.T. Hayes, Harald Drewes (USGS), and F. E. Kottlowski (NMBMMR) could not corroborate the reported occurrence of coal in these areas. Lithologic units in these areas include conglomerate, sandstone, a dn shale of the Tertiary Skunk Ranch Formation (Paleocene to Eocene), limestone-cobble conglomerate, shale, and arkosic sandstone of the Ringbone Formation (Late Cretaceous and early Tertiary), marine limestone of the U-Bar Formation (Early Cretaceous), and interbedded sandsotne, siltstone, and shale of the Mojado Formation (Late Cretaceous).

Cretaceous Geology

Cretaceous sedimentation and paleogeography in southeastern Arizona and southewestern New Mexico was first studied by Hayes (12970). Mack (1987), who drew much of his information from Hayes (1970), reported that Cretaceous sedimentation reflects two stages and tectonic events. These two distinct stages of tectonism correspond to the three lithologic intervals shown in **figure 7-23**. The first stage of sedimentation occurred from Aptian to middle Albian time, and corresponds with the lower and middle lithologic intervals. The second stage of sedimentation occurred from late Albian to Turonian time, and corresponds with the middle and upper lithologic intervals. Conformable lithologic units found throughout the study area were deposited during these two stages, and are divided into a lower siliciclastic interval corresponding to the Hell-to-Finish Formation, a middle carbonate-rich interval corresponding to the U-Bar Formation, and an upper siliciclastic interval corresponding to the Sarten and Mojado Formations. The Hell-to-Finish Formation consists of a basal conglomerate overlain by sandstone, siltstone, and shale with a maximum thickness of 700 m (Mack, 1987); it unconformably overlies Permian beds. The U-Bar Formation is a carbonate-rich interval consisting of interbedded limestone, shale, and sandstone; limestone intervals increase upward (Mack, 1987). Massive limestone at the top is

measured to be 1,067 m thick in the Big Hatchet Mountains (Zeller and Alper, 1965). The middle to late Albian Jojado Formation, transitional with the U-Bar Formation, consists of interbedded sandstone and shale and is about 1,500 m thick (Mack, 1987; Hyde, 1984). The Sarten Formation, unconforably overlying Permian rocks, is divided into a lower quartz sandstone member and an upper marine sandsotne member (Hyde, 1984) deposited contemporaneously in late Albian(?) time with the Beartooth Formation. Hyde (1984) defined eight facies int he Sarten Formation: fluvial, backshore, foreshore, upper shoreface, lower shoreface, upper offshore, lower offshoare, and a transgressive lag.

Tertiary Geology

At the end of Cretaceous time at the onset of the Laramide orogenty, a period of relative quiescence took place in the study area, with localized volcanic activity and sediment deposition into low-lying areas (Hayes, 1970; Drewes, 1968). Rapid subsidence and deposition of the Tertiary Skunk Ranch Formation was reported by Wilson (1970) and mapped by Lasky (1947), Zeller (1970), and Zeller and Alper (1965) in the Big and Little Hatchet Mountains; Zeller (1970) later incorporated the Skunk Ranch Formation into the Upper Cretaceous Ringbone Formation. Wilson (1991), who studied the depositional environments, stratigraphy, provenance, and age of the Skunk Ranch Formation, reintroduced the name, owing to the recognition of a major hiatus between the Skunk Ranch and Ringbone Formations. He reported approximately 590 m of Skunk Ranch Formation in the LIttle Hatchet Mountains. The lack of coal in these units may be attributed to rapid deposition onto a prograding delta during basin subsidence.

Conclusions

Tertiary and Cretaceous rocks in the study area do not contain coal resources and were not assessed in this report. Lower Cretaceous rocks in the study area are non-coal-bearing limestone, conglomerate, sandsotne, siltstone, and shale of the Hell-to-Finish, U-Bar, Mojado, and Sarten Formations; Tertiary non-coal-bearing rocks are predominantly sandstone, siltstone, shale, conglomerate, and limestone units of the Ringbone and Skunk Ranch Formations and volcanic rocks of the Hidalgo Volcanics. Although Cretaceous and Tertiary rock units are coal-bearing in other parts of the State, the tectonic and sedimentary history during deposition in the study area precludes the formation of coal. References pertaining to the paleoenvironments of depostion and tectonic setting of these rocks, in addition to the above sited references, include Basabilvazo, 1991; Donnan, 1987; Mack and others, 1988; and Wallin, 1983.

OIL AND GAS RESOURCES

by Susan Bartsch-Winkler

The Mimbres Resource Area is within the Southern Arizona-Southwestern New Mexico (Hidalgo, Luna, and Doña Ana Counties) and South-Central New Mexico (Grant County) petroleum provinces of Dolton and others, (1981), and there are no oil and gas fields within the study area. Large high percentages and great thicknesses of carbonate rocks and shales were laid down in Cambrian to Mississippian time in the region, and major basins were formed in Early Permian/Pennsylvanian time (Pedregosa and Orogrande basins) and late Tertiary time (Jornada del Muerto). These basins were subsequently deformed in Mesozoic and Cenozoic time, and have superimposed basins that are thicker than the Paleozoic basins. Laramide and later, rift-related structural features provide opportunities for both stratigraphic and structural traps for petroleum. Combined thicknesses of Paleozoic, Mesozoic, and Tertiary rocks are greater than 10,000 ft (Ryder, 1983). The study area is considered a frontier area in terms of petroleum exploration (Ryder, 1983).

Paleozoic rock units, which are equivalent to units within the Permian Basin of southeastern New Mexico that are source or producing units, are targets for petroleum exploration in the Pedregosa Basin in southwestern New Mexico. Paleozoic units that are targets include Cambrian through Mississippian rocks, Pennsylvanian and Permian rocks (7,500 ft thick), and Lower Cretaceous rocks (as much as 15,000 ft thick)(Greenwood and others, 1977). Tertiary sedimentary and volcanic rocks are as much as 6,000 ft thick (Thompson and others, 1978). Structural complications brought on by Laramide tectonism have produced potential structural traps for petroleum, but the rock units are not uniformly distributed (Ryder, 1983). Laramide features have probably been destroyed by Tertiary and later Basin-and-Range tectonism and volcanism.

In the southern Jornada del Muerto, Mesilla Basin, and westernmost Tularosa Basin areas of the Rio Grande Rift (within the Mimbres Resource Area), sedimentary rocks attain a thickness of as much as 10,000 ft (Ryder, 1983). Pre-rift rocks are Paleozoic in age, consisting mostly of Cambrian through Mississippian carbonates and shales (Kottlowski, 1971; Greenwood and others, 1977). Tularosa Basin overlies the central part of the Pennsylvanian-Permian Orogrande Basin, but the Mesilla and Jornada del Muerto are located on its western edge. Tularosa Basin contains as much as 3,500 ft of Pennsylvanian rocks and 3,000 ft of Permian rocks. Mesilla and Jornada del Muerto Basins each contain about 2,000 ft of Pennsylvanian rocks. Mesilla Basin contains about 3,000 ft of Permian rocks, while the Jornada del Muerto Basin has about 2,000 ft. Each of the basins holds about 1,000 ft of Cretaceous rocks, and the Mesilla basin additionally holds about 700 ft of Jurassic rocks (Thompson and Bieberman, 1975; Greenwood and others, 1977).

Tertiary rocks total about 3,000 ft in the Jornada del Muerto basin (Sanford, 1968), 6,000 ft in Tularosa Basin (McLean, 1970) and 12,000 ft in Mesilla basin (Thompson and Bieberman, 1975).

According to Ryder (1983), Pennsylvanian and Permian shale and limestone rocks are present in thermally mature basins including the Pedregosa, Tularosa, Mesilla and Jornada del Muerto basins, and have resulted in oil and gas shows. Geochemical studies in the Pedregosa Basin (KCM No. 1 Forest Federal, and Humble No. 1 State BA drill holes, as well as outcrops near the wells) indicate that the Pennsylvanian and Permian rocks have a maximum weight percent organic carbon value of slightly less than 1 ahd kerogen types which are gas prone (Cernock, 1977; Cernock and Bayliss, 1977; Thompson, 1980). Potentially, the burial history of Pedregosa Basin is favorable for gas generation (based on the Conodont Alteration Index of rocks in the wells that are proximal to plutons). Oil and gas shows in pre-Pennsylvanian rocks of Pedregosa and Mesilla Basins may have a source in the Percha Shale (Thompson and others, 1978; Thompson and Bieberman, 1975). In addition, the organic-rich Jurassic unit in the Mesilla Basin, although limited, may be a petroleum source rock (Thompson and Bieberman, 1975).

Reservoir rocks--

In the Pedregosa Basin, prospective targets for petroleum include the mainly the Epitaph Dolomite, Concha Limestone, and Horquilla Limestone; secondary targets include the U-Bar Formation, Mojado Formation, El Paso Limestone, Montoya Dolomite, and Fusselman Dolomite (Thompson and others, 1978). Both stratigraphic and structural traps may be present.

In the Mesilla, Jornada del Muerto, and Tularosa basins, the primary targets include the Magdalena Group and San Andres Limestone; secondary targets are the El Paso Limestone, Montoya Dolomite and Fusselman Dolomite (Greenwood and others, 1977; Thompson and others, 1978). Both stratigraphic and structural traps are present, particularly truncation traps (Kottlowski, 1971; Foster and Grant, 1974). In addition, in the Mesilla Basin, Lower Cretaceous sandstone rocks are potential traps (Foster and Grant, 1974).

APPENDIX A
REFERENCES-

compiled by Susan Bartsch-Winkler
and Margaret A. Clemenson
U.S. Geological Survey
Denver, CO 80225

Abramson, B.S., 1981, The mineralizing fluids responsible for skarn and ore formation at the Continental Mine, Fierro, New Mexico, in light of REE analyses and fluid inclusion studies: New Mexico Institute of Mining and Technology, unpublished Master's thesis, 143 p.

Ackermann, H.D., Pankratz, L.W., and Dansereau, D.A., 1982, A comprehensive system for interpreting seismic-refraction arrival time data using interactive computer methods: U.S. Geological Survey Open-File Report 82-1065, 265 p.

Ackermann, H.D., Pankratz, L.W., and Dansereau, D.A., 1986, Resolution of ambiguities of seismic refraction traveltime curves: Geophysics, v. 51, no. 2, p. 223-235.

Ackermann, H.D., Pankratz, L.W., and Klein, D.P., 1994, Six regionally extensive upper-crustal seismic refraction profiles in southwest New Mexico: U.S. Geological Survey Open-File Report 94-695, 18 p., 1 plate, scale approximately 1:635,000.

Adkins, 1933, The geology of Texas, part 2, in The Mesozoic systems in Texas: Texas University, Bulletin 3232, p. 239-518, 15 figs.

Agey, W.W., Batty, J.V., Knutson, E.G., and Hanson, G.M., 1959, Operations of manganese-ore-purchasing depots at Deming, New Mexico, and Wenden, Arizona: U.S. Bureau of Mines Report of Investigations 5462, 18 p.

Agezo, F.L., and Norman, D.I., 1993, Mineralogy, alteration, and fluid inclusion study of the Lordsburg Mining District, Hidalgo County, New Mexico: New Mexico Geological Society Spring Meeting, Proceedings, p. 28.

Agezo, F.L., and Norman, D.I., 1994, Mineralogy, alteration, and fluid inclusion study of the Lordsburg Mining District, Hidalgo County, New Mexico: Society for Mining, Metallurgy, and Exploration, Inc., 1994 Annual Meeting and Exhibit, Program with Abstracts, p. 116.

Agurkis, E.N., 1977, Depositional history of the Piankasha Sequence (Upper Devonian) southern Arizona and southwestern New Mexico: Arizona State University, unpublished Master's thesis, unknown p.

Ahmad, S.N., and Rose, A.W., 1980, Fluid inclusions in porphyry and skarn ore at Santa Rita, New Mexico: Economic Geology, v. 75, no. 2, p. 229-250.

Albritton, C.C., and Nelson, V.E., 1943, Lead, zinc, and copper deposits of the Organ district, New Mexico (with a supplement on the occurrence of bismuth): U.S. Geological Survey Open-File Report 43, 39 p.

Albritton, C.C., Jr., and Smith, J.F., Jr., 1957, The Texas lineament, *in* Relaciones entre la tectonica y la sedimentación: International Geological Congress, 20th, Mexico, D.F., 1956 [Trabajos], v. 2, sec. 5, p. 501-518.

Aldrich, M.J., Jr., 1974a, Structural development of the Hanover-Fierro pluton, southwestern New Mexico: Geological Society of America Bulletin, v. 85, no. 6, p. 963-968.

Aldrich, M.J., Jr., 1974b, Santa Rita-Hanover axis, New Mexico--Laramide structure with a late Tertiary Basin and Range trend [abs.]: Geological Society of America Abstracts with Programs, v. 6, no. 5, p. 421.

Aldrich, M.J., Jr., 1976, Geology and flow directions of volcanic rocks of the North Star Mesa quadrangle, Grant County, New Mexico, *in* Elston, W.E., and Northrop, S.A., eds., Cenozoic volcanism in southwestern New Mexico: New Mexico Geological Society Special Publication No. 5, p. 79-81.

Aldrich, M.J., Jr., 1978, Subsurface extensions of the Santa Rita-Hanover axis; A major early Tertiary structure, New Mexico: Geology, v. 6, no. 6, p. 373-376.
Aldrich, M.J., Jr., Chapin, C.E., and Laughlin, A.W., 1986, Stress history and tectonic development of the Rio Grande rift, New Mexico: Journal of Geophysical Research, v. 91, no. B6, p. 6199-6211.
Aldrich, M.J., Jr., and Laughlin, A.W., 1981, Age and location of volcanic centers ≤3.0 m.y. old in Arizona, New Mexico, and the Trans-Pecos area of west Texas: Los Alamos National Laboratory Map LA-8812, scale 1:1,000,000.
Aldrich, M.J., Jr., and Laughlin, A.W., 1984, A model for the tectonic development of the southeastern Colorado Plateau boundary: Journal of Geophysical Research, v. 89, no. B12, p. 10,207-10,218.
Aldridge, B.N., and Hales, T.A., 1984, Floods of November 1978 to March 1979 in Arizona and west-central New Mexico: U.S. Geological Survey Water-Supply Paper 2241, 149 p.
Alford, D.E., 1986, Origin of the Hembrillo succession of Proterozoic-age San Andres Mountains, south-central New Mexico [abs.]: New Mexico Geology, v. 8, no. 3, p. 68.
Alford, D.E., 1987, Geology and geochemistry of the Hembrillo Canyon succession, San Andres Mountains, Sierra and Doña Ana Counties, New Mexico: Socorro, New Mexico Institute of Mining and Technology, unpublished Master's thesis, 180 p.
Alford, J.J., 1982, San Vicente Arroyo: Annals of the Association of American Geographers, v. 72, no. 3, p. 398-403.
Allison, J.W., and Ove, W.E., 1957, A report on an airbourne survey and ground investigations at Silver City, New Mexico: U.S. Atomic Energy Commission, Report RME-1081, 15 p.
Allmandinger, R.J., 1974, A source of ore-forming fluids at the Hansonburg mining district, central New Mexico: Geological Society of America Abstracts with Programs, v. 6, no. 7, p. 633.
Altaner, S.P., Fitzpatrick, J.J., Krohn, M.D., Bethke, P.M., Hayba, D.O., Goss, J.A., and Brown, Z.A., 1988, Ammonium in alunites: American Mineralogist, v. 93, p. 145-152.
American Geological Institute, 1977, Gary, Margaret, McAfee, Robert, Jr., and Wolf, Carol L., eds., Glossary of Geology, *with a foreward by* Ian Campbell: Washington, D.C., American Geological Institute, 4th printing, 805 p., bibliography 52 p.
American Petroleum Institute and American Gas Association, 1980, Reserves of crude oil, natural gas liquids, and natural gas in the United States and Canada, v. 34: American Petroleum Institute and American Gas Association, Washington, D.C., 253 p.
Anderson, E.C., 1957, The metal resources of New Mexico and their economic features through 1954: New Mexico Bureau of Mines and Mineral Resources Bulletin 39, 183 p.
Anderson, C.A., and Creasey, S.C., 1958, Geology and ore deposits of the Jerome area, Yavapai County, Arizona: U.S. Geological Survey Professional Paper 308, 185 p.
Anderson, O.J., 1980, Abandoned or inactive uranium mines in New Mexico: New Mexico Bureau of Mines and Mineral Resources Open File Report 148, 778 p.
Anonymous, 1973, Summary of Cenozoic geology of the area, *in* Hoffer, J.M., ed., The geology of southcentral Doña Ana County, New Mexico: El Paso Geological Society, 7th Annual Fieldguide, p. 1-25.
Anonymous, 1982, Boliden to explore Pinos Altos deposit: Mining Congress Journal, v. 68, no. 5, p. 7.
Anonymous, 1984, "Rock Hound" State Park: Rock and Gem, v. 14, no. 10, p. 24-27.
Anonymous, 1987, Diatomite, no skeletons in the cupboard: Industrial Minerals, no. 236, p. 22-39.
Anthony, E.Y., Barnes, C.G., Chen, W., Hoffer, J.M., Keller, G.R., Marsaglia, K.M., McLemore, V.T., Seeley, J.M., Seward, M.A., Shannon, W.M., and Thomann, W.F., 1991, Examples of modern rift volcanism and Proterozoic anorogenic magmatism--The Potrillo volcanic field of southern New Mexico and the Franklin Mountains of west Texas, *in* Julian, Betsy, and Zidek, Jiri, Field guide to geologic excursions in New Mexico and adjacent areas of Texas and Colorado: New Mexico Bureau of Mines and Mineral Resources Bulletin 137, p. 1-19.

Appelt, R.M., 1993, Paleomagnetic correlation of ignimbrites in the Steeple Rock mining district, southwestern New Mexico [abs.]: Geological Society of America Abstracts with Programs, v. 25, no. 5, p. 4.

Armin, R.A., 1987, Sedimentology and tectonic significance of Wolfcampian (Lower Permian) conglomerates in the Pedregosa Basin; southeastern Arizona, southwestern New Mexico, and northern Mexico: Geological Society of America Bulletin, v. 99, no. 1, p. 42-65.

Armstrong, A.K., 1962, Stratigraphy and paleontology of the Mississippian System in southwestern New Mexico and adjacent southeastern Arizona: New Mexico Bureau of Mines and Mineral Resources Memoir 8, 99 p.

Armstrong, A.K., 1970, Mississippian stratigraphy and geology of the northwestern part of the Klondike Hills, southwestern New Mexico, *in* Woodward, L.A., ed., Guidebook of the Tyrone-Big Hatchet Mountains-Florida Mountains Region: New Mexico Geological Society, 21st Annual Field Conference, p. 59-63.

Armstrong, A.K., and Mamet, B.L., 1978, The Mississippian System of southwestern New Mexico and southeastern Arizona, *in* Callender, J.F., Wilt, J.C., and Clemons, R.E., eds., Land of Cochise, Southeastern Arizona: New Mexico Geological Society, *in cooperation with* Arizona Geological Society, 29th Annual Field Conference, p. 183-192.

Armstrong, A.K., and Mamet, B.L., 1988, Mississippian (Lower Carboniferous) biostratigraphy, facies, and microfossils, Pedregosa Basin, southeastern Arizona and southwestern New Mexico: U.S. Geological Survey Bulletin 1826, 40 p.

Armstrong, A.K., Mamet, B.L., and Repetski, J.E., 1980a, The Mississippian system of New Mexico and southern Arizona, *in* Fouch, T.D., and Magathan, E.R., Paleozoic paleogeography of the west–central United States; Rocky Mountain paleogeography symposium 1: Society of Economic Paleontologists and Mineralogists, Rocky Mountain Section, Denver, Colo., p. 82–99.

Armstrong, A.K., Mamet, B.L., and Repetski, J.E., 1980b, The Mississippian system of New Mexico and southern Arizona [abs.]: American Association of Petroleum Geologists Bulletin, v. 64, no. 5, p. 671.

Armstrong, A.K., and Silberman, M.L., 1974, Geologic map of the central Peloncillo Mountains, Hidalgo County, New Mexico: U.S. Geological Survey Open-File Report 74-11.

Armstrong, A.K., Silberman, M.L., Todd, V.R., Hoggatt, W.C., and Carten, R.B., 1978, Geology of central Peloncillo Mountains, Hidalgo County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 158, 19 p., map scale 1:24,000.

Armstrong, F.E., Evans, G.C., and Fletcher, G.E., 1971, Tritiated water as a tracer in the dump leaching of copper: U.S. Bureau of Mines Report of Investigations 7510, 39 p.

Arnold, E.C., Hill, J.M., and Donaldson, D.A., 1981, Oil and gas, *in* Arnold, E.C., and Hill, J.M., compilers, New Mexico energy resources '80: New Mexico Bureau of Mines and Mineral Resources Circular 181, p. 10-21.

Arnold, E.C., Hill, J.M., Donaldson, D.A., Martinez, L.B., Foster, R.W., and Gutjahr, A.L., 1978, Oil and gas, *in* Arnold, E.C., compiler, New Mexico's energy resources '77: New Mexico Bureau of Mines and Mineral Resources Circular 167, p. 9-27.

Ash, S.R., and Read, C.B., 1976, North American species of Tempskya and their stratigraphic significance: U.S. Geological Survey Professional Paper 874, 42 p.

Ashley, R.P., 1982, Occurrence model for enargite-gold deposits, *in* Erickson, R.L., ed., Characteristics of mineral deposit occurrences: U.S. Geological Survey Open-File Report 82-795, p. 144-147.

Aubele, J.C., Crumpler, L.S., Loeber, K.N., and Kudo, A.M., 1976, Maare and tuff rings of New Mexico, *in* Woodward, L.A., and Northrop, S.A., eds., Tectonics and mineral resources of southwestern North America: New Mexico Geological Society Special Publication No. 6, p. 109-114.

Austin, G.S., 1994, Pumice mining and environmental concerns in New Mexico: New Mexico Geology, v. 16, p. 1–6.

Austin, G.S., Kottlowski, F.E., and Siemers, W.T., 1982, Industrial minerals of New Mexico in 1981, *in* Austin, G.S., compiler, Industrial rocks and minerals of the southwest: New Mexico Bureau of Mines and Mineral Resources Circular 182, p. 9-16.

Axelrod, D.I., 1975, Tertiary floras from the Rio Grande Rift, *in* Seager, W.R., Clemons, R.E., and Callender, J.F., ed., Guidebook of the Las Cruces Country: New Mexico Geological Society, 26th Annual Field Conference, p. 85-88.

Bachman, G.O., and Hayes, P.T., 1958, Stratigraphy of Upper Pennsylvanian and lower Permian rocks in the Sand Canyon area, Otero County, New Mexico: Geological Society of America Bulletin, v. 69, no. 6, p. 689– 700.

Bachman, G.O., and Mehnert, H.H., 1978, New K-Ar dates and the late Pliocene to Holocene geomorphic history of the central Rio Grande region, New Mexico: Geological Society of America, Bulletin, v. 89, no. 2, p. 283-292.

Bachman, G.O., and Myers, D.A., 1963, Geology of the Bear Peak NE quadrangle, Doña Ana County, New Mexico: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-374, scale 1:31,680.

Bachman, G.O., and Myers, D.A., 1969, Geology of the Bear Peak area, Doña Ana County, New Mexico: U.S. Geological Survey Bulletin 1271-C, 46 p.

Bachman, G.O., and Myers, D.A., 1975, The Lead Camp Limestone and its correlatives in south-central New Mexico, *in* Seager, W.R., Clemons, R.E., and Callender, J.F., eds., Guidebook of the Las Cruces Country: New Mexico Geological Society, 26th Annual Field Conference, p. 105-108.

Backer, H.A., 1974, Geology of the Gila fluorspar district (Brock Canyon volcanic complex), Grant County, New Mexico (abs.): New Mexico Geological Society, Guidebook to the 25th Field Conference, p. 377.

Bagby, W.C., Menzie, W.D., Mosier, D.L., and Singer, D.A., 1986, Grade and tonnage model of carbonate-hosted Au-Ag, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 175-177.

Bahar, Dana, 1991, Stratigraphy of the base-surge deposits at the southern end of Kilbourne Hole maar, southern New Mexico: Proceedings of the 1990 New Mexico Geological Society meeting; New Mexico Geology, v. 13, no. 2, p. 39.

Bahar, Dana, and McCurry, Michael, 1989, Base-surge deposits at Kilbourne Hole maar, southern New Mexico, *in* Chapin, C.E., and Zidek, Jiri, eds., Field excursions to volcanic terranes in the western United States, Volume I--Southern Rocky Mountain region: New Mexico Bureau of Mines and Mineral Resources Memoir 46, p. 180.

Bahlburg, W.C., 1977, Depositional environments of the Tamaroa Sequence (Mississippian) of southeastern Arizona, southwestern New Mexico, and northern Mexico: Arizona State University, unpublished Master's thesis, unknown p.

Bailey, R.B., 1994 (revised), Ecoregions of the United States: U.S. Department of Agriculture Forest Service map, scale 1:7,500,000.

Baker, Tanya G., 1993, Mobility of heavy metals in soils and tailings at the Hanover and Bullfrog tailings sites, Silver City, New Mexico: New Mexico Bureau of Mines and Mineral Resources Open File Report 393 (also New Mexico Geological Society Spring Meeting, Proceedings, p. 28).

Baldridge, W.S., Bartov, Y., and Kron, A., 1983, Geologic map of the Rio Grande rift and southeastern Colorado plateau, New Mexico, and Arizona, *in* Riecker, R.E., ed., Rio Grande rift--Tectonics and magmatism (2nd ed.): Washington, D.C., American Geophysical Union, scale 1:500,000.

Baldridge, W.S., Damon, P.E., Shafiqullah, M., and Birdwell, R.J., 1980, Evolution of the central Rio Grande rift, New Mexico--New potassium-argon ages: Earth and Planetary Science Letters, v. 51, no. 2, p. 309-321.

Baldridge, W.S., Perry, F.V., Vaniman, D.T., Nealey, L.D., Leavy, B.D., Laughlin, A.W., Kyle, P., Bartov, Y., Steinitz, G., and Gladney, E.S., 1989, Magmatism associated with lithospheric extension--Middle to Late Cenozoic magmatism of the southeastern Colorado Plateau and central Rio Grande rift, New Mexico and Arizona, *in* Chapin, C.E., and Zidek, Jiri, eds., Field excursions to volcanic terranes in the western United States, Volume I--Southern Rocky Mountain region: New Mexico Bureau of Mines and Mineral Resources Memoir 46, p. 187-202.

Balk, Robert, 1961, Geologic map of Tres Hermanas Mountains: New Mexico Bureau of Mines and Mineral Resources Geologic Map 16, scale 1:48,000.

Ballantyne, J.M., 1981, Geochemistry of hydrothermal sericite and chlorite: University of Utah, unpublished Ph. D. dissertation, 146 p.

Ballman, D.L., 1960, Geology of the Knight Peak area, Grant County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 70, 39 p.

Ballmer, G.J., 1932, Native tellurium from northwest of Silver City, New Mexico: American Mineralogist, v. 17, no. 10, p. 491-492.

Banister, J.R., and Hereford, W.V., 1991, Observed high-altitude pressure waves from an underground and a surface explosion: Journal of Geophysical Research (Atmospheres), v. 96, no. 3, p. 5185-5193.

Barker, J.M., 1988, Travertine quarries and deposits in New Mexico [abs.]: New Mexico Geology, v. 10, no. 3, p. 68.

Barker, J.M., Austin, G.S., and Sivils, D.J., 1995, Travertine in New Mexico--Commercial deposits and otherwise [abs.]: Programs and abstracts, Thirty-first forum on the Geology of Industrial Minerals: Socorro, New Mexico Bureau of Mines and Mineral Resources, p. 12-14.

Barnes, V.E., 1977 project director, Del Rio Sheet, Geologic Atlas of Texas: Austin, University of Texas, Bureau of Economic Geology.

Barnes, C.G., Ensenat, S.E., and Hoover, J.D., 1991, Mineralogy and geochemistry of Eocene intrusive rocks and their enclaves, El Paso area, Texas and New Mexico: American Mineralogist, v. 76, nos. 7-8, p. 1306-1318.

Barrie, Ferdinand, 1976, A Bouguer gravity anomaly map of the Franklin Mountains, New Mexico and Texas, *in* LeMone, D.V., and Lovejoy, E.M.P., Symposium on the Franklin Mountains: El Paso Geological Society Quinn Memorial Volume, p. 161-163.

Barua-Remy, V.F., 1950, Gravimetric separation of accessory minerals of the rocks of the Ground Hog Mine, Vanadium, New Mexico: Bloomington, Indiana University, unpublished Master's thesis, unknown p.

Basabilvazo, G.T., 1991, Stratigraphy, depositional environments, and sediment dispersal pathways of the Upper Cretaceous Ringbone Formation in the Little Hatchet Mountains of southwestern New Mexico: Las Cruces, New Mexico State University, unpublished Master's thesis, 157 p.

Basler, J.A., and Alary, L.J., 1968, Quality of the shallow ground water in the Rincon and Mesilla Valleys, New Mexico and Texas: U.S. Geological Survey Open-File Report, 30 p.

Beard, R.D., 1987, Geology and geochemistry of the central part of the Gold Hill mining district, Hidalgo and Grant Counties, New Mexico: Albuquerque, University of New Mexico, unpublished Master's thesis, 157 p.

Beard, R.D., and Brookins, D.G., 1986, Geology and geochemistry of the central part of the Gold Hill mining district, Hidalgo and Grant Counties, New Mexico [abs.]: New Mexico Geology, v. 8, no. 3, p. 68.

Beard, R.D., and Brookins, D.G., 1988, Geology and mineral deposits of the Gold Hills, Hidalgo and Grant Counties, New Mexico, *in* Mack, G.H., Lawton, T.F., and Lucas, S.G., eds., Cretaceous and Laramide tectonic evolution of southwestern New Mexico: New Mexico Geological Society, 39th Annual Field Conference, Guidebook, p. 203-210.

Bedinger, M.S., Langer, W.H., and Reed, J.E., 1989, Ground-water hydrology, *in* Bedinger, M.S., Sargent, K.A., and Langer, W.H., eds., Studies of geology and hydrology in the Basin and Range Province, Southwestern United States, for isolation of high-level radioactive waste; characterization of the Rio Grande region, New Mexico and Texas: U.S. Geological Survey Professional Paper 1370-C, p. C27-C34.

Bedinger, M.S., Sargent, K.A., and Johnson, W.D., Jr., 1989, Introduction, *in* Bedinger, M.S., Sargent, K.A., and Langer, W.H., eds., Studies of geology and hydrology in the Basin and Range Province, Southwestern United States, for isolation of high-level radioactive waste; characterization of the Rio Grande region, New Mexico and Texas: U.S. Geological Survey Professional Paper 1370-C, p. C1-C6.

Beehner, T.S., 1990, Burial of fault scarps along the Organ Mountains fault, south-central New Mexico: Association of Engineering Geologists Bulletin, v. 27, no. 1, p. 1-9.

Behnken, F.H., 1977, Conodont determinations, KCM No. 1 Forest Federal well, Hidalgo County, New Mexico, *in* Thompson, Sam, III, compiler, Geology, petroleum source rocks, and thermal metamorphism in KCM No. 1 Forest Federal well, Hidalgo County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 152, p. 25-28.

Bell, A.R., 1983, Victorio Mountain molybdenum/tungsten project, Luna County, New Mexico: Gulf Mineral Resources Co., unpublished report on file at the Anaconda Geological Document Collection, American Heritage Center, University of Wyoming, No. 43303.01, 150 p.

Belle, E., Cornell, W.C., and Norland, W.D., 1988, Thermal alteration indices vs. "pure" geochemistry--Two tales of a rock [abs.]: American Association of Petroleum Geologists Bulletin, v. 72, no. 1, p. 98.

Belt, C.B., Jr., 1955, A petrographic and alteration study of the Hanover-Fierro intrusive, New Mexico: New York, Columbia University, unpublished Master's thesis, unknown p.

Benjovsky, T.D., 1946, The New Mexico Ricolite Company, Telegraph Mining District, Grant Couty, New Mexico: New Mexico Bureau of Mines and Mineral Resources Open File Report 14, 11 p.

Bergendahl, M.H., 1962, Gold, *in* Mineral and water resources of New Mexico, 89th U.S. Congress, 1st session, Senate Committee on Interior and Insular Affairs: p. 131-139.

Berger, B.R., 1986a, Descriptive model of carbonate-hosted Au-Ag, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 175.

Berger, B.R., 1986b, Descriptive model of epithermal quartz-alunite Au, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 158.

Berger, B.R., and Eimon, P.I., 1983, Conceptual models of epithermal precious-metals deposits, *in* Shanks, W.C., III, ed., Cameron volume on unconventional mineral deposits: Society of Mining Engineers, p. 191-205.

Berger, B.R., and Henley, R.W., 1989, Advances in the understanding of epithermal gold-silver deposits, with special reference to the western United States, *in* Keays, R.R., Ramsay, W.R.H., and Groves, D.I., eds., The geology of gold deposits--The perspective in 1988: Economic Geology Monograph, no. 6, p. 405-423.

Berman, R.G., and Reid, J.B., Jr., 1976, The deep-seated evolution of highly undersaturated basaltic magmas; evidence from kaersutite-gabbro inclusions, West Potrillo Mountains, New Mexico [abs.]: Eos, American Geophysical Union, Transactions, v. 57, no. 4, p. 354-355.

Bersch, M.G., 1977, Petrography and geology of the southern West Potrillo Basalt Field, Doña Ana County, New Mexico: El Paso, University of Texas, unpublished Master's thesis, 60 p.

Beyer, J.B., McCurry, M., and Seager, W.R., 1985, A preliminary interpretation of some compositional and textural gradients across a mafic facies of the Organ Needle quartz monzonite, New Mexico [abs.]: New Mexico Geology, v. 7, no. 3, p. 64.

Bieberman, R.A., and Weber, R.H., 1969, New Mexico resources map: New Mexico Bureau of Mines and Mineral Resources, scale 1:1,000,000.

Bieberman, R.W., and Chavez, R.R., compilers, 1995a, Petroleum exploration map of Hidalgo County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Petroleum Exploration Mapno. 23, scale 1:126,720. (Updated annually)

Bieberman, R.W., and Chavez, R.R., compilers, 1995b, Petroleum exploration map of Doña Ana County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Petroleum Exploration Map no. 17, scale 1:126,720. (Updated annually)

Bieberman, R.W., and Chavez, R.R., compilers, 1995c, Petroleum exploration map of Grant County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Petroleum Exploration Map no. 25, scale 1:126,720. (Updated annually)

Bieberman, R.W., and Chavez, R.R., compilers, 1995d, Petroleum exploration map of Luna County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Petroleum Exploration Map no. 22, scale 1:126,720. (Updated annually)

Biggerstaff, B.P., 1974, Geology and ore deposits of the Steeple Rock-Twin Peaks area, Grant County, New Mexico: El Paso, University of Texas, unpublished Master's thesis, 85 p.

Bikerman, Michael, 1972, New K-Ar ages on volcanic rocks from Catron and Grant Counties, New Mexico: Isochron/West, no. 3, p. 9-12.

Bilodeau, W.L., and Lindberg, F.A., 1983, Early Cretaceous tectonics and sedimentation in southern Arizona, southwestern New Mexico, and northern Sonora, Mexico, *in* Reynolds, M.W., and Dolly, E.D., eds., Mesozoic paleogeography of west-central United States: Society of Economic Paleontologists and Mineralogists, Rocky Mountain Section, p. 173-188.

Bisdorf, R.J., 1985, Schlumberger sounding results in the Hueco Bolson, New Mexico: U.S. Geological Survey Open-File Report 85-0607, 120 p.

Black, J.E., Mancuso, T.K., and Gant, J.L., 1991, Geology and mineralization at the Rawhide Au-Ag deposit, Mineral County, Nevada, *in* Raines, G.L., Lisle, R.E., Shafer, R.W., and Wilkinson, W.H., eds., Geology and ore deposits of the Great Basin, Symposium Proceedings: Reno, Geological Society of Nevada and U.S. Geological Survey, p. 1123-1142.

Blake, W.P., 1894, Alunogen and bauxite of New Mexico with notes on the geology of the Upper Gila Region: American Geologist, v. 14, p. 196.

Blake, W.P., 1895, Alunogen and bauxite of New Mexico with notes on the geology of the Upper Gila Region [abs.]: American Institute of Mining Engineers Transactions, v. 24, p. 571-573.

Blankenship, J.C., 1972, Stratigraphy and petrology of the El Paso Formation (Lower Ordovician) in the Silver City Range, New Mexico: University of Houston, Texas, unpublished Master's thesis, 145 p.

Blazek, M.C., 1980, New Mexico's copper roses: Rockhound, v. 9, no. 3, p. 20-21.

Bliss, J.D., ed., 1992, Developments in mineral deposit modeling: U.S. Geological Survey Bulletin 2004, 168 p.

Bliss, J.D., and Cox, D.P., 1986, Grade and tonnage model of polymetallic veins, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 125-129.

Bliss, J.D., and Orris, G.J., 1992, Grade and tonnage model of feldspar in pegmatites, *in* Orris, G.J., and Bliss, J.D., eds., Industrial mineral deposit models--Grade and tonnage models: U.S. Geological Survey Open-File Report 92-437, p. 14-16.

Bliss, J.D., Sutphin, D.M., Mosier, D.L., and Allen, M.S., 1992, Grade-tonnage and target-area models of Au-Ag-Te veins associated with alkalic rocks: U.S. Geological Survey Open-File Report 92208, 15 p.

Blood, C.C., 1916, Piños Altos district, Grant County, New Mexico: Mining World, v. 45, p. 659-660.

Bogart, L.E., 1953, The Hueco (Gym) Limestone, Luna County, New Mexico: Albuquerque, University of New Mexico, unpublished Master's thesis, 91 p.

Bonham, H.F., Jr., 1969, Geology and mineral deposits of Washoe and Storey Counties, Nevada: Nevada Bureau of Mines and Geology Bulletin 70, 140 p.

Bonham, H.F., Jr., 1985, Characteristics of bulk-minable gold-silver deposits in Cordilleran and island-arc settings, *in* Tooker, E.W., ed., Geologic characteristics of sediment- and volcanic-hosted disseminated gold deposits--search for an occurrence model: U.S. Geological Survey Bulletin 1646, p. 71-77.

Bookstrom, A.A., 1981, Tectonic setting and generation of Rocky Mountain porphyry molybdenum deposits, *in* Dickinson, W.R., and Payne, W.D., Relations of tectonics to ore deposits in the southern Cordillera: Arizona Geological Society Digest, v. 14, p. 215-226.

Bornhorst, T.J., 1980, Major- and trace-element geochemistry and mineralogy of upper Eocene to Quaternary volcanic rocks of the Mogollon-Datil volcanic field, southwestern New Mexico: Albuquerque, University of New Mexico, unpublished Ph. D. dissertation, 1108 p.

Bornhorst, T.J., 1986, Granophile elements in mid-Cenozoic calc-alkalic rhyolitic volcanic rocks, Mogollon-Datil volcanic field, southwestern New Mexico, *in* Taylor, R.P., and Strong, D.F., eds., Recent advances in the geology of granite-related mineral deposits: The Canadian Institute of Mining and Metallurgy, Special Volume 39, p. 331-341.

Bornhorst, T.J., 1988, Character of mid-Cenozoic andesites, basaltic andesites, and related volcanic rocks, Mogollon-Datil volcanic field, southwestern New Mexico, *in* Drexler, J.W., and Larson, E.E., Cenozoic volcanism in the Southern Rocky Mountains updated--A tribute to Rudy C. Epis--Part 2: Colorado School of Mines Quarterly, v. 83, p. 1-13.

Bornhorst, T.J., Jones, D.P., Elston, W.E., Damon, P.E., and Shafiqullah, M., 1982, New radiometric ages on volcanic rocks from the Mogollon-Datil field, southwestern New Mexico: Isochron/West, no 35, p. 13-14.

Böse, E., 1906, Excursion au Cerro de Muleros, International Geological Congress 10, Guide Exc. 20, 24 p.

Böse, E., 1910, Monografia geologia y paleontologia del Cerro de Muleros; Bol. del Instituto Geologicao de Mexico, no. 25, 193 p.

Bowers, W.E., 1960, Geology of the East Potrillo Hills, Doña Ana County, New Mexico: Albuquerque, University of New Mexico, unpublished Master's thesis, 67 p.

Bowie, M.R., 1985, Geology of the Dripping Springs Valley chabazite and related zeolite deposits, Southeast Arizona and Southwest New Mexico: Socorro, New Mexico Institute of Mining and Technology, unpublished Master's thesis, 139 p.

Bowie, M.R., 1986, Commercial potential of the Buckhorn, New Mexico, clinoptilolite deposit [abs.]: New Mexico Geology, v. 8, no. 3, p. 68.

Bowie, M.R., Barker, J.M., and Peterson, S.L., 1987, Comparison of selected zeolite deposits of Arizona, New Mexico, and Texas, *in* Peirce, H.W., ed., Proceedings of the 21st Forum on the Geology of Industrial Minerals: Arizona Bureau of Geology and Mineral Technology Special Paper 4, p. 90-105.

Bowlds, L.S., 1989, Tracking down the Early Permian: Geotimes, v. 34, no. 5, p. 12-14.

Bowsher, A.L., 1967, The Devonian System of New Mexico: Tulsa Geological Society Digest, v. 35, p. 259-276.

Boyd, F.S., Jr., and Wolfe, H.D., 1953, Recent investigations of radioactive occurrences in Sierra, Doña Ana and Hidalgo Counties, New Mexico: New Mexico Geological Society, 4th Annual Field Conference, Guidebook, p. 141-142.

Brady, B.T., 1989, Mineral and energy resources, *in* Bedinger, M.S., Sargent, K.A., and Langer, W.H., eds., Studies of geology and hydrology in the Basin and Range Province, Southwestern United States, for isolation of high-level radioactive waste; characterization of the Rio Grande region, New Mexico and Texas: U.S. Geological Survey Professional Paper 1370-C, p. C35-C42.

Braile, L.W., Hinze, W.J., von Frese, R.R.B., and Keller, G.R., 1989, Seismic properties of the crust and uppermost mantle of the conterminous United States and adjacent Canada: Geological Society of America Memoir 172, p. 655-680.

Breck, D.W., 1974, Zeolite molecular sieves: New York, John Wiley and Sons, 771 p.
Brennan, D.J., and Thompson, Sam, III, 1989, Oil and gas exploration wells drilled to Precambrian basement in southeastern Arizona and southwestern New Mexico, *in* Drewes, Harald, and Dyer, Russ, 1989, Tectonics of the eastern part of the Cordilleran Orogenic Belt, Chihuahua, New Mexico, and Arizona, Field Trip Guidebook T121, 28th International Geological Congress: American Geophysical Union, Washington, D.C., p. 64-70.
Briggs, I.C., 1974, Machine contouring using minimum curvature: Geophysics, v. 39, no. 1, p. 39-48.
Briggs, J.P., 1981, Mines and prospects map of the Hells Hole further planning area (RARE II), Greenlee County, Arizona, and Grant County, New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map MF-1344-C, scale 1:62,500.
Briggs, J.P., 1982, Mineral investigation of the Hells Hole Roadless area, Greenlee County, Arizona and Grant County, New Mexico: U.S. Bureau of Mines Open File Report MLA 137-82, 22 p.
Briskey, J.A., 1986, Descriptive model of southeast Missouri Pb-Zn, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 220-221.
Broadhead, R.F., 1982, Oil and gas discovery wells drilled in New Mexico in 1981: New Mexico Geology, v. 4, no. 2, p. 17-19, 32.
Broadhead, R.F., 1983a, Oil and gas discovery wells drilled in New Mexico in 1982: New Mexico Geology, v. 5, no. 2, p. 30-34.
Broadhead, R.F., 1983b, Oil and gas discovery wells drilled in New Mexico in 1983: New Mexico Geology, v. 6, p. 21-27.
Broadhead, R.F., 1985, Oil and gas discovery wells drilled in New Mexico in 1984: New Mexico Geology, v. 7, no. 2, p. 35-39.
Broadhead, R.F., 1988, Oil and gas discovery wells drilled in New Mexico in 1987: New Mexico Geology, v. 10, no. 3, p. 54-60.
Brobst, D.A., 1994, Barium minerals, *in* Carr, D.D., Industrial Minerals and Rocks: Society for Mining, Metallurgy, and Exploration, Inc., Littleton, Colorado, 6th edition, p. 125-134.
Broderick, J.C., 1984, The geology of Granite Hill, Luna County, New Mexico: El Paso, University of Texas, unpublished Master's thesis, 90 p.
Bromfield, C.S., and Wrucke, C.T., 1961, Reconnaissance geologic map of the Cedar Mountains, Grant and Luna Counties, New Mexico: U.S. Geological Survey Mineral Investigations Field Studies Map MF-159, scale 1:62,500.
Brookins, D.G., 1974, Radiometric age determinations from the Florida Mountains, New Mexico: Geology, v. 2, no. 11, p. 555-557.
Brookins, D.G., 1980a, Geochronologic evidence for Paleozoic plutonic activity in Florida Mountains, New Mexico [abs.]: American Association of Petroleum Geologists Bulletin, v. 64, no. 5, p. 681-682.
Brookins, D.G., 1980b, Paleozoic plutonism from southern New Mexico--Evidence from the Florida Mountains: Geophysical Research Letters, v. 7, no. 10, p. 741-744.
Brookins, D.G., and Corbitt, L.L., 1974, Preliminary Rb-Sr study of igneous rocks of the Florida Mountains, New Mexico [abs.]: American Geophysical Union, Transactions (EOS), v. 55, no. 4, p. 470-471.
Brookins, D.G., Rautman, C.E., and Corbitt, L.L., 1978, Uranium and thorium abundances and whole rock chemistry of the Florida Mountains, New Mexico--Preliminary study: New Mexico Energy Institute Report 77-1104-C, 22 p.
Brookins, D.G., Rautman, C.E., and LeRoy, L., 1978, A study of silicic plutonic rocks in the Zuni and Florida Mountains to evaluate the possible occurrence of disseminated uranium and thorium deposits--Uranium and thorium abundances and whole-rock chemistry of the Florida Mountains, New Mexico: University of New Mexico Energy Institute Report NMEI 77-1104-B, 46 p.

Brooks, W.E., Adrian, B.M., and Erlich, Olga, 1988, Analytical results and sample locality map of rock samples from the Cowboy Spring Wilderness Study Area, Hidalgo County, New Mexico: U.S. Geological Survey Open-File Report 88-0211, 9 p.

Brooks, W.E., Hassemer, J.R., Duval, J.S., Hanna, W.F., and Scott, D.C., 1989, Mineral resources of Cowboy Spring Wilderness Study Area, Hidalgo County, New Mexico: U.S. Geological Survey Bulletin 1735-F, p. F1-F11.

Brooks, W.E., and Ratté, J.C., 1985, Geologic map of Bear Mountain quadrangle, Grant County, New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map MF-1782, scale 1:24,000.

Brophy, G.P., Scott, E.S., and Snellgrove, R.A., 1962, Sulfate Series II, solid solution between alunite and jarosite: American Mineralogist, v. 47, p. 112-126.

Brown, G.A., 1982, Geology of the Mahoney mine-Gym Peak, Florida Mountains, Luna County, New Mexico: Las Cruces, New Mexico State University, unpublished Master's thesis, 82 p.

Brown, G.A., and Clemons, R.E., 1983a, Florida Mountains section of southwest New Mexico overthrust belt--A reevaluation: New Mexico Geology, v. 5, no. 2, p. 26-29.

Brown, G.A., and Clemons, R.E., 1983b, Florida Mountains, southwest New Mexico--Part of Cordilleran overthrust belt or foreland block uplift?: AAPG annual convention with divisions SEPM/EMD/DPA, American Association of Petroleum Geologists Bulletin, v. 67, no. 3, p. 432.

Brown, L.D., Chapin, C.E., Sanford, A.R., Kaufman, S., and Oliver, J.E., 1980, Deep structure of the Rio Grande Rift from seismic reflection profiling: Journal Geophysical Research, v. 85, p. 4773-4800.

Brown, L.F., 1977, A gravity survey of central Doña Ana County, New Mexico: Las Cruces, New Mexico State University, unpublished Master's thesis, 56 p.

Broxton, D., 1978, Uranium hydrogeochemical and stream sediment reconnaissance of the Tularosa NTMS quadrangle, New Mexico: Los Alamos Scientific Laboratory Report 7217 (GJBX 104-78), 85 p.

Bruno, L., 1987, Depositional environments and diagenesis of the Cable Canyon Sandstone and Upham Dolomite, Ordovician of southern New Mexico: University of Houston, Texas, unpublished Master's thesis, 278 p.

Bruno, Lawrence, and Chafetz, H.S., 1988, Depositional environment of the Cable Canyon Sandstone--A mid-Ordovician sandwave complex from southern New Mexico, *in* Mack, G.H., Lawton, T.F., and Lucas, S.G., eds., Cretaceous and Laramide tectonic evolution of southwestern New Mexico: Guidebook, New Mexico Geological Society, 39th Annual Field Conference, p. 127-134.

Bryan, K., 1938, Geology and ground-water conditions of the Rio Grande depression in Colorado and New Mexico; Rio Grande Joint Investigations in the Upper Rio Grande Basin in Colorado, New Mexico, and Texas: Washington National Resources Commission, Regional Planning, Report Number 6, 196-225.

Bryant, D.L., and McClymonds, N.E., 1961, Permian Concha Limestone and Rainvalley Formation, southeastern Arizona: American Association of Petroleum Geologists Bulletin, v. 45, no. 8, p. 1324–1333.

Buchanan, L.J., 1981, Precious metal deposits associated with volcanic environments in the southwest, *in* Dickinson, W.R., and Payne, W.D., Relations of tectonics to ore deposits in the southern Cordillera: Arizona Geological Society Digest, v. 14, p. 237-262.

Buck, B.J., and Mack, G.H., 1992, Paleosols and paleoflora of the Upper Cretaceous (Maastrichtian) McRae Formation, south-central New Mexico, and their implication to paleoclimate [abs.]: New Mexico Geological Society Proceedings Volume, 1992 Annual Spring Meeting, p. 11.

Budding, A.J., and Condie, K.C., 1975, Precambrian rocks of the Sierra Oscura and northern San Andres Mountains, *in* Seager, W.R., Clemons, R.E., and Callender, J.F., eds., Guidebook of the Las Cruces Country: New Mexico Geological Society, 26th Annual Field Conference, p. 89-93.

Budding, A.J., Pitrat, C.W., and Smith, C.T., 1960, Geology of the southeastern part of the Chama basin: New Mexico Geological Society, 11th Annual Field Conference, Guidebook, p. 78–92,
Bullard, F.J., 1953, Polymorphinidae of the Cretaceous (Cenomanian) Del Rio Shale [Texas]: Journal of Paleontology, v. 27, no. 3, p. 338–346.
Burchard, E.F., 1911, Fluorspar in New Mexico (Fluorite Ridge): Mining and Scientific Press, July 15, 1911, p. 74-76.
Bureau of Land Management, 1983a, Department of the Interior Final Environmental Statement; Upper Gila, San Simon, (document of the BLM) unpaginated.
Bureau of Land Management, 1983b, Energy minerals leasing and rangeland management in the Las Cruces/Lordsburg resource area: (document of the BLM) unpaginated.
Bureau of Land Management, 1983c, Las Cruces/Lordsburg resource area: U.S. Bureau of Land Management, Las Cruces District Office, 166 p.
Bureau of Land Management, 1984, Las Cruces District Wilderness; Final Environmental Assessment (document of the BLM) unpaginated.
Burke, W.H., Kenny, G.S., Otto, J.B., and Walker, R.D., 1963, Potassium–argon dates, Socorro and Sierra Counties, New Mexico, *in* Guidebook of the Socorro region, New Mexico: New Mexico Geological Society, 14th Field Conference, p. 224.
Burnham, C.W., 1959, Metallogenic provinces of the southwestern United States and northern Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 65, 76 p.
Burt, D.M., 1982, Skarn deposits--Historical bibliography through 1970: Economic Geology, v. 77, no. 4, p. 755-763.
Bush, F.V., 1915, Meerschaum deposits of New Mexico: Engineering and Mining Journal, v. 99, p. 941-943.
Bushman, F.X., 1955, Ground-water data for Dwyer quadrangle, Grant and Luna Counties, New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 37, 18 p.
Bushnell, H.P., 1953, Geology of the McRae Canyon area, Sierra County, New Mexico: Albuquerque, University of New Mexico, unpublished Master's thesis, 106 p.
Bushnell, H.P., 1955, Mesozoic stratigraphy of south-central New Mexico, *in* Fitzsimmons, J.P., ed., South-central New Mexico: New Mexico Geological Society, *in cooperation with* the Roswell Geological Society, 6th Annual Field Conference, p. 81-87.
Bussod, Y.A., and Irving, A.J., 1981, Thermal and rheologic history of the upper mantle beneath the southern Rio Grande Rift--Evidence from Kilbourne Hole xenoliths: papers presented to the Conference on the processes of planetary rifting, Lunar and Planetary Institute Contribution 457, p. 145-148.
Bussod-Giles, Y.A., and Williams, D.R., 1991, Thermal and kinematic model of the southern Rio Grande Rift--Inferences from crustal and mantle xenoliths from Kilbourne Hole, New Mexico, *in* Gangi, A.F., ed., World Rift Systems: Tectonophysics, v. 197, nos. 2-4, p. 373-389.
Butler, A.P., Jr., Finch, W.I., and Twenhofel, W.S., 1962, Epigenetic uranium deposits in the United States, exclusive of Alaska and Hawaii: U.S. Geological Survey Mineral Investigations Resource Map MR-21, scale 1:3,168,000.
Butler, W.C., 1988, The rationale for assessment of undiscovered, economically recoverable oil and gas in south-central New Mexico; a geologic overview and play analysis of two favorable areas: U.S. Geological Survey Open-File Report 88-0450-B, 134 p.
Cady, F.H., 1938, Thermal metamorphism of sedimentary rocks of Hanover, New Mexico: Evanston, Ill., Northwestern University, unpublished Master's thesis, unknown p.
Calder, S.R., 1982, The geology of, and known mineral occurrences within, Wilderness Study Area 4-60, Vanar Hills-Peloncillo Mountains: Arizona Bureau of Geology and Mineral Technology Open-file Report 83-6, 18 p.

Callender, J.F., Seager, W.R., and Swanberg, C.A., 1983, Late Tertiary and Quaternary tectonics and volcanism: New Mexico State University Energy Institute Geothermal Resources of New Mexico--Scientific Map Series, scale 1:500,000.

Callender, J.F., Wilt, J.C., Clemons, R.E., and James, H.L., eds., 1978, Land of Cochise, southeastern Arizona; New Mexico Geological Society, 29th Annual Field Conference, Guidebook, 372 p.

Cameron, C.M., 1994, The destruction of the past--Nonrenewable cultural resources: Nonrenewable Resources, v. 3, no. 1, p. 6-24.

Cardinali, Mauro, Guzzetti, Fausto, and Brabb, E.E., 1990, Escarpments and landslide scarps--Preliminary maps showing landslide deposits and related features in New Mexico: U.S. Geological Survey Open-File Report 90-293, 4 sheets, scale 1:500,000.

Cargo, D.N., 1959, Mineral deposits of the Granite Gap area, Hidalgo County, New Mexico: University of New Mexico, unpublished Master's thesis, 70 p.

Carlisle, D., Merifield, P.M., Orme, A.R., Kohl, M.S., Kolker, O., and Lunt, O.R., 1978, The distribution of calcretes and gypcretes in southwestern United States and their uranium favorability based on a study of deposits in western Australia and southwest Africa (Nambia): U.S. Department of Energy, Report GJBX-29-78, 274 p.

Carpenter, D.W., 1958, Hydrothermal alteration at Santa Rita, New Mexico: University Park, Pennsylvania State University, unpublished Master's thesis, unknown p.

Carson Helicopters, Inc., 1981, NURE aerial gamma ray and magnetic survey of portions of New Mexico, Arizona, and Texas [includes El Paso and Las Cruces quadrangles]: U.S. Department of Energy, Grand Junction Office Report GJBX-412(81), 7 vols.

Carten, R.B., Silberman, M.L., and Armstrong, A.K., 1974, Geology, trace-metal anomalies and base-metal mineralization in the central Peloncillo Mountains, Hidalgo County, New Mexico [abs.]: New Mexico Institute of Mining and Technology, Symposium on base metal and fluorspar districts of New Mexico, p. 7 (also New Mexico Geological Society, Annual Field Conference, Guidebook 25, p. 378).

Carter, M. D., 1977, Gem materials, *in* Mineral and water resources of New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 87, p. 267-276.

Cather, S.M., 1990, Stress and volcanism in the northern Mogollon-Datil volcanic field, New Mexico--Effects of the post-Laramide tectonic transition: Geological Society of America Bulletin, v. 102, p. 1447-1458.

Cather, S.M., and Johnson, B.D., 1984, Eocene tectonics and depositional setting of west-central New Mexico and eastern Arizona: New Mexico Bureau of Mines and Mineral Resources Circular 192, 33 p.

Cathey, Carl, Hoenig, Margaret, Oden, James, and Rubio, Jesus, 1976a, Magnetic survey of east side of Campus Pluton, *in* LeMone, D.V., and Lovejoy, E.M.P., Symposium on the Franklin Mountains: El Paso Geological Society Quinn Memorial Volume, p. 165-176.

Cathey, Carl, Hoenig, Margaret, Oden, James, and Rubio, Jesus, 1976b, Magnetic resolution of the Three Sisters--Preliminary report, *in* LeMone, D.V., and Lovejoy, E.M.P., Symposium on the Franklin Mountains: El Paso Geological Society Quinn Memorial Volume, p. 177-180.

Cathles, L.M., 1981, Fluid flow and genesis of hydrothermal ore deposits, *in* Skinner, B.J., ed., Economic Geology, Seventy-Fifth Anniversary Volume, 1905-1980: Economic Geology Publishing Company, p. 424-457.

Cato, Travis, Jr., 1985, Minerals of the Palm Park barite deposit, Hatch, New Mexico [abs.]: New Mexico Geology, v. 7, no. 2, p. 42.

Cernock, P.J., 1977, Hydrocarbon source-rock evaluation study, Humble Oil and Refining Company No. 1 State BA well, Hidalgo County, New Mexico (report by Geochem Laboratories, Inc.): New Mexico Bureau of Mines and Mineral Resources Open File Report 97, 10 p.

Cernock, P.J., and Bayliss, G.S., 1977, Organic geochemical analyses of drill cuttings from KCM No. 1 Forest Federal well, Hidalgo County, New Mexico, *in* Thompson, Sam, III, compiler, Geology, petroleum source rocks, and thermal metamorphism, in KCM No. 1 Forest Federal well, Hidalgo County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 152, p. 37-47.

Chafetz, H.S., 1982, The Upper Cretaceous Beartooth Sandstone of southwestern New Mexico--A transgressive deltaic complex on silicified paleokarst: Journal of Sedimentary Petrology, v. 52, no. 1, p. 157-169.

Chafetz, H.S., Meredith, J.C., and Kocurek, G., 1986, The Cambro-Ordovician Bliss Formation, southwestern New Mexico, U.S.A.; Progradational sequences on a mixed siliciclastic and carbonate shelf: Sedimentary Geology, v. 49, nos. 3-4, p. 201-221.

Chaiffetz, M.S., Kocurek, G., and Cornell, W., 1979, First report of *Chitinozoa* from the Upper Devonian Percha Shale, SW New Mexico [abs.], *in* Bryant, V.M., ed., Abstracts of the Proceedings of the Tenth Annual meeting of the American Association of Stratigraphic Palynologists: Palynology, v. 3, p. 280-281.

Chang, J., Miller, K.C., Thompson III, S., and Keller, G.R., 1994, Relationship of Laramide and Basin and Range structures in the Pedregosa Basin, southwestern New Mexico [abs.], *in* Geologic activities in the 90s, Southwest Section of AAPG 1994, Ruidoso, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 150, p. 128-129.

Chapin, C.E., 1971a, The Rio Grande Rift, Part I--Modifications and additions, *in* James, H.L., ed., Guidebook of the San Luis Basin, Colorado: New Mexico Geological Society, 22nd Annual Field Conference, p. 191-201.

Chapin, C.E., 1971b, K-Ar age of the La Jara Peak Andesite and its possible significance to mineral exploration in the Magdalena mining district, New Mexico: Isochron/West, no. 2, p. 43-44.

Chapin, C.E., 1974, Three-fold tectonic subdivision of the Cenozoic in the Cordilleran foreland of Colorado, New Mexico, and Arizona [abs.]: Geological Society of America Abstracts with Programs, v. 6, no. 5, p. 433.

Chapin, C.E., 1979, Evolution of the Rio Grande rift--A summary, *in* Riecker, R., ed., Rio Grande rift--Tectonics and magmatism: American Geophysical Union, Monograph, p. 1-5.

Chapin, C.E., and Cather, S.M., 1981, Eocene tectonics and sedimentation in the Colorado Plateau-Rocky Mountain area, *in* Dickinson, W.R., and Payne, W.D., Relations of tectonics to ore deposits in the southern Cordillera: Arizona Geological Society Digest, v. 14, p. 173-198.

Chapin, C.E., Elston, W.E., and James, H.L., eds., 1978a, Field guide to selected cauldrons and mining districts of the Datil-Mogollon volcanic field, New Mexico: New Mexico Geological Society Special Publication 7, 149 p.

Chapin, C.E., Elston, W.E., and James, H.L., 1978b, Supplemental road log No. 4; Gila mining district, *in* Chapin, C.E., Elston, W.E., and James, H.L., eds., Field guide to selected cauldrons and mining districts of the Datil-Mogollon volcanic field, New Mexico: New Mexico Geological Society Special Publication 7, p. 86-87.

Chapin, C.E., and Seager, W.R., 1975, Evolution of the Rio Grande Rift in the Socorro and Las Cruces area, *in* Seager, W.R., Clemons, R.E., and Callender, J.F., eds., Guidebook of the Las Cruces Country; New Mexico Geological Society, 26th Annual Field Conference, p. 297-321.

Chapin, C.E., Siemers, W.T., and Osburn, G.R., 1975, Summary of radiometric ages of New Mexico rocks: New Mexico Bureau of Mines and Mineral Resources Open File Report 60, extensive compilation kept up to date [inspection only at NMBMMR].

Chapman-Fahey, J.L., 1993, Late Cretaceous volcanism in south-central New Mexico --Conglomerates of the McRae and Love Ranch Formations [abs.]: Geological Society of America Cordilleran Section and Rocky Mountain sections, Abstracts with Programs, v. 25, no. 5, p. 20.

Chaturvedi, L., 1980a, Analysis of geological and geophysical logs of two geothermal exploration wells drilled on NMSU land, Las Cruces New Mexico, *in* Icerman, L., Starkey, A., and Trentman, N., eds., State-coupled Low Temperature Geothermal Resource Assessment Program, fiscal year 1979--Final technical report: p. 10.1-10.24.

Chaturvedi, L., 1980b, Estimation of geothermal potential from geothermal aquifer characteristics and groundwater temperature changes with time: International Geological Congress (Paris, 1980); Resumes, v. 3, no. 26, p. 1096.

Chaturvedi, L., 1980c, New Mexico State University geothermal production well, *in* Icerman, L., Starkey, A., and Trentman, N., eds., State-coupled Low Temperature Geothermal Resource Assessment Program, fiscal year 1979--Final technical report: p. 11.1-11.40.

Chaturvedi, L., and Ramos, A.M., 1979, Geothermal hydrology and hydrogeology of Animas Basin and KGRA, southwestern New Mexico [abs.]: Geological Society of America Abstracts with Programs, v. 11, no. 7, p. 400-401.

Chavez, W.X., Jr., 1991, Paragenesis of bismuth and associated silver-bearing phases, Pinos Altos District, Grant County, New Mexico [abs.]: 11th Annual New Mexico Mineral Symposium, Proceedings, p. 5.

Chidester, A.H., Engel, A.E.J., and Wright, L.A., 1964, Talc resources of the United States: U.S. Geological Survey Bulletin 1167, p. 37-38, 45-47.

Christiansen, P.W., 1974, The story of mining in New Mexico: New Mexico Bureau of Mines and Mineral Resources, Scenic Trip 12, 112 p.

Christiansen, R.L., and Lipman, P.W., 1972, Cenozoic volcanism and plate-tectonic evolution of western United States, pt. 2, Late Cenozoic: Philosophical Transactions Royal Society of London, Series A, v. 271, p. 249-284.

Christianson, N.I., 1989, Seismic velocities, *in* Charmichael, R.S., ed., CRC practical handbook of physical properties of rocks and minerals: Boca Raton, Florida, CRC Press, p. 429-546.

Cima, J.A., 1978, Physical properties of selected scoria cones in New Mexico: Socorro, New Mexico Institute of Mining and Technology, unpublished Master's thesis, 89 p.

Clark, K.F., 1962a, Hypogene zoning in the Lordsburg mining district, Hidalgo County, New Mexico: Albuquerque, University of New Mexico, unpublished Master's thesis, 136 p.

Clark, K.F., 1962b, Hypogene zoning in the Lordsburg mining district, Hidalgo County, New Mexico [abs.], *in* Ash, S.R., and Davis, L.V., eds., Ruidoso Country (New Mexico): New Mexico Geological Society, 15th Annual Field Conference, p. 186-187.

Clark, K.F., 1970, Zoning, paragenesis, and temperatures of formation in the Lordsburg district, *in* Woodward, L.A., ed., Copper, gold, and silver ores, New Mexico: Guidebook of the Tyrone-Big Hatchet Mountains-Florida Mountains region, New Mexico Geological Society, p. 107-113.

Clark, Sandra, and Orris, G.J., 1991, Vein barite, *in* Orris, G.J., and Bliss, J.D., eds., Some industrial mineral deposit models: U.S. Geological Survey Open-File Report 91-11A, p. 19-20.

Clarke, F.W., 1886, Report of work done in the division of chemistry and physics mainly during the fiscal year 1884-1885: U.S. Geological Survey Bulletin 0027, 80 p.

Clarke, F.W., Hillebrand, W.F., Ransome, F.L., Penfield, S.L., Lindgren, W., Steiger, G., and Schaller, W.T., 1905, Plumbojarosite, Cooks Peak district, New Mexico, *in* Contributions to Mineralogy: U.S. Geological Survey Bulletin 262, p. 35-36.

Clauter, D.A., 1981, A paleomagnetic study of the Organ Mountain intrusive: EOS, Transactions, American Geophysical Union, v. 62, no. 45, p. 855.

Clemons, R.E., 1975, Petrology of the Bell Top Formation, *in* Seager, W.R., Clemons, R.E., and Callender, J.F., eds., Guidebook of the Las Cruces Country: New Mexico Geological Society, 26th Annual Field Conference, p. 123-130.

Clemons, R.E., 1976a, Geology of east half Corralitos Ranch quadrangle, New Mexico: New Mexico Bureau of Mines and Mineral Resources Geologic Map 36, scale 1:24,000.

Clemons, R.E., 1976b, Sierra de las Uvas ash-flow field, south-central New Mexico, *in* Woodward, L.A., and Northrop, S.A., eds., Tectonics and mineral resources of southwestern North America: New Mexico Geological Society Special Publication 6, p. 115-121.
Clemons, R.E., 1977, Geology of west half Corralitos Ranch quadrangle, New Mexico: New Mexico Bureau of Mines and Mineral Resources Geologic Map 44, scale 1:24,000.
Clemons, R.E., 1979, Geology of Good Sight Mountains and Uvas Valley, southwest New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 169, 31 p., map scale 1:48,000, cross-sections.
Clemons, R.E., 1982a, Volcanic development of Little Florida Mountains, southwest New Mexico [abs.]: Geological Society of America Abstracts with Programs, v. 14, no. 3, p. 108.
Clemons, R.E., 1982b, Petrography and age of plutonic rocks of Florida Mountains, New Mexico--Preliminary report: New Mexico Geology, v. 4, no. 3, p. 33-38.
Clemons, R.E., 1982c, Geology of the Massacre Peak quadrangle: New Mexico Bureau of Mines and Mineral Resources Map 51, scale 1:24,000.
Clemons, R.E., 1982d, Geology of Florida Gap quadrangle, Luna County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Geologic Map 52, scale 1:24,000.
Clemons, R.E., 1984, Geology of Capitol Dome quadrangle, Luna County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Geologic Map 56, scale 1:24,000.
Clemons, R.E., 1985, Geology of South Peak Quadrangle: New Mexico Bureau of Mines and Mineral Resources Geologic Map no. 59, scale 1:24,000.
Clemons, R.E., 1986a, Another look at oil and gas exploration potential in southwestern New Mexico [abs.]: New Mexico Geology, v. 8, no. 3, p. 67.
Clemons, R.E., 1986b, Simplified geologic map of the Fanglomerate of Little Florida Mountains, *in* Hoffer, J., ed., Geology of southcentral New Mexico: El Paso Geological Society Guidebook 17, 165 p.
Clemons, R.E., 1986c, Petrography and stratigraphy of Seville-Trident exploration wells near Deming, New Mexico: New Mexico Geology, v. 8, no. 1, p. 5-11.
Clemons, R.E., 1987, Mineralization, alteration, and igneous activity in the Florida Mountains, southwestern New Mexico: New Mexico Geological Society Spring Meeting, Socorro, Proceedings, p. 42.
Clemons, R.E., 1988a, Lost Padre Mine--Fact or fiction? [abs.]: Ninth Annual New Mexico Mineral Symposium, Proceedings, p. 7.
Clemons, R.E., 1988b, Distribution of dolomite in Lower Ordovician El Paso Formation [abs.]: American Association of Petroleum Geologists Bulletin, v. 72, no. 1, p. 99.
Clemons, R.E., 1989a, Geology of the Florida Mountains, New Mexico, *in* Drewes, Harald, and Dyer, Russ, eds., Tectonics of the eastern part of the Cordilleran Orogenic Belt, Chihuahua, New Mexico, and Arizona: Field Trip Guidebook T121, 28th International Geological Congress, Washington, D.C., American Geophysical Union, p. 16-24.
Clemons, R.E., 1989b, Geology of the Florida Mountains, southwest New Mexico: New Mexico Bureau of Mines and Mineral Resources Memoir 43, ---.
Clemons, R.E., 1989c, The Ellenburger-El Paso connection; Lower Ordovician shelf carbonates, *in* Cunningham, B.K., and Cromwell, D.W., The lower Paleozoic of West Texas and southern New Mexico; modern exploration concepts: Society of Economic Paleontologists and Mineralogists, Permian Basin Chapter, v. 89-31, p. 85-104.
Clemons, R.E., 1993, Petrographic analysis of Cenozoic-Mesozoic-Permian well cuttings from two exploration wells in south-central New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 203, 28 p.
Clemons, R.E., and Brown, G.A., 1983, Geology of Gym Peak quadrangle, Luna County, New Mexico: Geologic Map 58, scale 1:24,000.

Clemons, R.E., Christiansen, P.W., and James, H.L., 1980, Southwestern New Mexico: Scenic Trips to the Geologic Past, v. 10, 119 p.
Clemons, R.E., Hawley, J.W., Hoffer, J.M., and Seager, W.R., 1975, Second day, road log from Las Cruces to the Sierra de las Uvas and Aden volcanic area and return, *in* Guidebook of the Las Cruces Country: New Mexico Geological Society, 26th Annual Field Conference, p. 17-34.
Clemons, R.E., and Mack, G.H., 1988a, Geology of southwestern New Mexico, *in* Mack, G.H., Lawton, T.F., and Lucas, S.G., eds., Cretaceous and Laramide tectonic evolution of southwestern New Mexico: New Mexico Geological Society, 39th Annual Field Conference, Guidebook, p. 45-57.
Clemons, R.E., and Mack, G.H., 1988b, First-day road log, west flank of Florida Mountains, *in* Mack, G.H., Lawton, T.F., and Lucas, S.G., eds., Cretaceous and Laramide tectonic evolution of southwestern New Mexico: New Mexico Geological Society, 39th Annual Field Conference, Guidebook, p. 1-2.
Clemons, R.E., and Seager, W.R., 1973a, Geology of Souse Springs quadrangle, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 100, 31 p., map scale 1:24,000.
Clemons, R.E., and Seager, W.R., 1973b, Cenozoic geology of the Goodsight-Cedar Hills volcanic-tectonic depression, *in* Hoffer, J.M., ed., The geology of southcentral Dona Ana County, New Mexico: El Paso Geological Society, 7th Annual Fieldguide, p. 50-55.
Clemons, R.E., and Seager, W.R., 1978, Supplemental road log no. 1; Road log from junction of New Mexico Highway 90 and U. S. Highway 180, Central to Las Cruces via Deming: in Chapin, C.E., Elston, W.E., James, H.L., eds., Field guide to selected cauldrons and mining districts of the Datil-Mogollon volcanic field, New Mexico: New Mexico Geological
Clifton, R.A., 1987, Natural and synthetic zeolites: U.S. Bureau of Mines Information Circular 9140, 21 p.
Clippinger, D.M., 1949, Barite of New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 21, 28 p.
Clippinger, D.M., and Gay, W.E., 1947, Pumice aggregate in New Mexico—its use and potentialities: New Mexico Bureau of Mines and Mineral Resources Bulletin 28, 56 p.
Clopine, W.W., 1988, Fusulinid zonation and stratigraphic analysis of the Derryan Series (Middle Pennsylvanian) in southern New Mexico-West Texas [abs.]: Geological Society of America Abstracts with Programs, v. 20, no. 7, p. 122.
Cobban, W.A., 1987, Ammonite faunas of the Sarten sandstone (Cretaceous), Luna County, New Mexico: U.S. Geological Survey Bulletin 1641-B, p. B1-B17.
Cobban, W.A., 1988, Tarrantoceras Stephenson and related ammonoid genera from Cenomanian (Upper Cretaceous) rocks in Texas and the Western Interior of the United States: U.S. Geological Survey Professional Paper 1473, 51 p.
Cobban, W.A., and Hook, S.C., 1981, New Turrilitid ammonite from mid-Cretaceous (Cenomanian) of southwest New Mexico; *in* Hook, S.C., ed., Contributions to mid-Çretaceous paleontology and stratigraphy of New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 180, p. 22-29.
Cobban, W.A., and Hook, S.C., 1983, *Pseudaspidoceras pseudonodosoides* (Choffat); common Upper Cretaceous guide fossil in southwest New Mexico: Annual Report of the New Mexico Bureau of Mines and Mineral Resources, 1981-1982, p. 37-40.
Cobban, W.A., Hook, S.C., and Kennedy, W.J., 1989, Upper Cretaceous rocks and ammonite faunas of southwestern New Mexico: New Mexico Bureau of Mines and Mineral Resources Memoir 45, 137 p.
Condie, K.C., 1978, Geochemistry of Proterozoic granitic plutons from New Mexico, U.S.A.: Chemical Geology, v. 21, p. 131-149.

Condie, K.C., 1981, Precambrian rocks of southwestern United States and adjacent Mexico: New Mexico Bureau of Mines and Mineral Resources Resource Map 13, scale 1:1,000,000.
Condie, K.C., and Budding, A.J., 1979, Geology and geochemistry of Precambrian rocks, central and south-central New Mexico: New Mexico Bureau of Mines and Mineral Resources Memoir 35, 58 p.
Coney, P.J., 1976, Structure, volcanic stratigraphy, and gravity across the Mogollon Plateau, New Mexico, *in* Elston, W.E., and Northrop, eds., Cenozoic volcanism in southwestern New Mexico: Socorro, New Mexico Geological Society Special Publication No. 5, p. 29-41.
Coney, P.J., 1978, The plate tectonic setting of southeastern Arizona: New Mexico Geological Society, *in* Callender, J.F., Wilt, J.C., and Clemons, R.E., eds., Land of Cochise, Southeastern Arizona: New Mexico Geological Society, *in cooperation with* Arizona Geological Society, 29th Annual Field Conference, p. 285-290.
Coney, P.J., 1981, Accretionary tectonics in western North America, *in* Dickinson, W.R., and Payne, W.D., Relations of tectonics to ore deposits in the southern Cordillera: Arizona Geological Society Digest, v. 14, p. 23-38.
Coney, P.J., and Reynolds, S.J., 1977, Cordilleran Benioff zones: Nature, v. 270, p. 403-406.
Contaldo, G.J., 1986, Earth fissures in the Deming area, Luna County, New Mexico [abs.]: New Mexico Geology, v. 8, no. 3, p. 70.
Contaldo, G.J., 1989, Earth fissures and land subsidence near Deming, New Mexico: Las Cruces, New Mexico State University, unpublished Master's thesis, 106 p.
Contaldo, G.J., and Mueller, J.E., 1988, Earth fissures in the Deming area, *in* Mack, G.H., Lawton, T.F., and Lucas, S.G., eds., Cretaceous and Laramide tectonic evolution of southwestern New Mexico: New Mexico Geological Society, 39th Annual Field Conference, Guidebook, p. 3-12.
Cook, F.A., McCullar, D.B., Decker, E.R., and Smithson, S.B., 1979, Crustal structure and evolution of the southern Rio Grande rift, *in* Riecker, R., ed., Rio Grande rift--Tectonics and magmatism: American Geophysical Union Monograph, p. 195-208.
Cook, K.H., Johnson, David, and Norman, D.I., [abst] 1985, Conodont color alteration--a possible exploration tool for ore deposits, *in* Eggleston, T.L., Epithermal deposits in New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 199, p. 51.
Cook, S.S., 1993, Supergene copper mineralization at the Tyrone mine, Grant County, New Mexico [abs.]: Society for Mining, Metallurgy and Exploration, Inc., 1993 Annual Meeting and Exhibit, Reno, February 15-18, 1993, Program with Abstracts, p. 139.
Cooley, B., 1958, Oil exploration in the area of the Franklin and Hueco Mountains: West Texas Geological Society Guidebook, 1958 Field Trip, p. 70-72.
Cooper, G.A., and Dutro, J.T., 1982, Devonian brachiopods of New Mexico: Bulletins of American Paleontology, v. 82–83, no. 315, 215 p.
Cooper, J.R., 1950, Johnson Camp area, Cochise County, Arizona; Chapter 3, Part 1, Arizona zinc and lead deposits, Arizona Bureau of Mines Bulletin no. 156, Geologic Series, no. 18, p. 30-39.
Cooper, J.R., 1959, Reconnaissance geologic map of southeastern Cochise County, Arizona: U.S. Geological Survey Miscellaneous Field Studies Map MF-0213, scale 1: 125,000.
Cooper, J.R., 1962, Bismuth in the United States, exclusive of Alaska and Hawaii: U.S. Geological Survey Mineral Investigations Resource Map MR-22, scale 1:3,168,000.
Cooper, J.R., and Silver, L.T., 1964, Geology and ore deposits of the Dragoon quadrangle, Cochise County, Arizona: U. S. Geological Survey Professional Paper 0416, 196 p.
Corbitt, L.L., 1971, Structure and stratigraphy of the Florida Mountains, New Mexico: Albuquerque, University of New Mexico, unpublished Ph. D. dissertation, 115 p.
Corbitt, L.L., 1974, Structure and stratigraphy of the Florida Mountains, *in* Corbitt, L.L., ed., Geology of the Florida Mountains, Luna County New Mexico: El Paso Geological Society, Guidebook 8, p. 16-29.

Corbitt, L.L., and Nials, F.L., 1975, Tectonic significance of the Pony Hills, Luna County, New Mexico, *in* Seager, W.R., Clemons, R.E., and Callender, J.F., eds., Guidebook of the Las Cruces Country: New Mexico Geological Society, 26th Annual Field Conference, p. 293-296.

Corbitt, L.L., Nials, F.L., and Varnell, R.J., 1977, Structure of Brockman Hills, southwestern New Mexico: American Association of Petroleum Geologists Bulletin, v. 61, no. 4, p. 601-607.

Corbitt, L.L., Nials, F.L., and Varnell, R.J., 1978, Laramide thrust faulting, Klondike Hills, southwestern New Mexico, *in* Callender, J.F., Wilt, J.C., Clemons, R.E., and James, H.L., eds., Land of Cochise, southeastern Arizona: New Mexico Geological Society, *in cooperation with* Arizona Geological Society, 29th Field Conference, Guidebook, p. 297-300.

Corbitt, L.L., Nials, F.L., and Varnell, R.J., 1981, Laramide structures in the Snake Hills, southwestern New Mexico, *in* Hoffer, J.M., and Hoffer, R.L., eds., Geology of the Border; southern New Mexico-northern Chihuahua: El Paso Geological Society, p. 83-85.

Corbitt, L.L., and Woodward, L.A., 1970, Thrust faults of the Florida Mountains, New Mexico, and their regional tectonic significance, *in* Woodward, L.A., ed., Guidebook of the Tyrone-Big Hatchet Mountains-Florida Mountains Region: New Mexico Geological Society, 21st Annual Field Conference, p. 69-74.

Corbitt, L.L., and Woodward, L.A., 1973a, Tectonic framework of the Cordilleran foldbelt in southwestern New Mexico: American Association of Petroleum Geologists Bulletin, v. 57, no. 11, p. 2207-2216.

Corbitt, L.L., and Woodward, L.A., 1973b, Upper Precambrian diamictite of Florida Mountains, southwestern New Mexico: Geological Society of America, Bulletin 84, p. 171-173.

Cordell, L., 1975, Combined geophysical studies at Kilbourne Hole maar, New Mexico, *in* Seager, W.R., Clemons, R.E., and Callender, J.F., eds., Guidebook of the Las Cruces Country: New Mexico Geological Society, 26th Annual Field Conference, p. 269-271.

Cordell, L.E., 1978, Regional geophysical setting of the Rio Grande rift: Geological Society of America, Bulletin 89, p. 1073-1090.

Cordell, L.E., 1983a, Aeromagnetic map of New Mexico: National Oceanographic and Atmospheric Administration, National Geophysical Data Center, Scientific Map Series, scale 1;500,000.

Cordell, L.E., 1983b, Composite Residual Total Intensity Aeromagnetic Map of New Mexico; available from the National Oceanic and Atmospheric Administration (NOAA), National Geophysical Data Center, Code E/GCI, 325 Broadway, Boulder, CO 80303.

Cordell, L.E., Keller, G.R., and Hildenbrand, T.G., 1982, Compete Bouguer gravity anomaly map of the Rio Grande rift, Colorado, New Mexico, and Texas: U.S. Geological Survey Geophysical Investigations Map GP-949, scale 1:1,000,000.

Cornell, W.C., and LeMone, D.V., 1987, The Anapra Sandstone of Cerro de Cristo Rey, Doña Ana County, New Mexico: New Mexico Journal of Science, v. 27, p. 123.

Correa, B.P., 1980, Fluorine and lithophile element mineralization in the Black Range and Sierra Cuchillo, New Mexico, *in* Burt, D.M., Sheridan, M.F., Bikun, J., Christiansen, E., Correa, B.P., Murphy, B., and Self, S., eds., Uranium mineralization in fluorine-enriched volcanic rocks--Final report: GJBX-225-80, p. 459-494.

Cowan, Chris, 1994, Notable miarolitics of the Organ Mountains [abs.]: New Mexico Geology, v. 16, n. 1, p. 15.

Cox, D.P., 1986a, Descriptive model of porphyry Cu, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 76.

Cox, D.P., 1986b, Descriptive model of porphyry copper, skarn-related, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 82.

Cox, D.P., 1986c, Descriptive model of porphyry Cu-Mo, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 115.

Cox, D.P., 1986d, Descriptive model of Zn-Pb skarn deposits, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 90.
Cox, D.P., 1986e, Descriptive model of Fe skarn deposits, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 94.
Cox, D.P., 1986f, Descriptive model of polymetallic veins, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 125.
Cox, D.P., 1986g, Descriptive model of sediment-hosted Cu, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 205.
Cox, D.P., 1986h, Descriptive model of W skarn deposits, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 55.
Cox, D.P., 1986i, Descriptive model of Besshi massive sulfide, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 136.
Cox, D.P., and Bagby, W.C., 1986a, Descriptive model of W veins, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 64.
Cox, D.P., and Bagby, W.C., 1986b, Descriptive model of Au-Ag-Te veins, *in* Cox, D.P., and Singer, D. A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 124.
Cox, D.P., and Singer, D.A., eds., 1986, Mineral deposit models: U.S. Geological Survey, Bulletin 1693, 379 p.
Cox, D.P., and Theodore, T.G., 1986, Descriptive model of Cu skarn deposits, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 86.
Craft, W.B., and Hanson, T.A., 1981, Finding mineral treasure with a metal detector: Rock and Gem, v. 11, no. 10, p. 36-37.
Craig, R., 1972, Stratigraphic correlation of the East Potrillo Mountains with Sierra de Juarez; The Stratigraphy and structure of Sierra de Juarez, Chihuahua, Mexico: El Paso Geological Society Annual Field Trip Guidebook 6, p. 17-18.
Creasey, S.C., 1967, Geologic map of the Benson quadrangle, Cochise and Pima Counties, Arizona: U.S. Geological Survey Miscellaneous Investigations Series I-0470, scale 1: 48,000.
Cross, C.W., 1899, *assisted by* Spencer, A.C., Description of the La Plata quadrangle, Colorado: U. S. Geological Survey Geologic Atlas, La Plata filio no. 60, 14 p, maps.
Cruz, R.R., 1974, Annual water-resources review, White Sands Missile Range, 1973--A basic data report: U.S. Geological Survey Open-File Report, 36 p.
Cruz, R.R., 1977, Annual water-resources review, White Sands Missile Range, 1976--A basic data report: U.S. Geological Survey Open-File Report 77-0330, 27 p.
Cruz, R.R., 1978, Annual water-resources review, White Sands Missile Range, New Mexico, 1977: U.S. Geological Survey Open-File Report 78-0553, 42 p.
Cruz, R.R., 1979, Annual water-resources review, White Sands Missile Range, New Mexico: U.S. Geological Survey Open-File Report 79-0985, 33 p.
Cruz, R.R., 1980, Annual water-resources review, White Sands Missile Range, New Mexico: U.S. Geological Survey Open-File Report 80-0753, 28 p.
Cruz, R.R., 1981, Annual water-resources review, White Sands Missile Range, New Mexico: U.S. Geological Survey Open-File Report 81-0921, 32 p.
Cruz, R.R., 1982, Annual water-resources review, White Sands Missile Range, New Mexico: U.S. Geological Survey Open-File Report 82-0757, 24 p.
Cruz, R.R., 1983, Annual water-resources review, White Sands Missile Range, New Mexico: U.S. Geological Survey Open-File Report 83-0695, 20 p.
Cruz, R.R., 1984, Annual water-resources review, White Sands Missile Range, New Mexico, 1983: U.S. Geological Survey Open-File Report 84-0720, 40 p.
Cruz, R.R., 1985, Annual water-resources review, White Sands Missile Range, New Mexico, 1984: U.S. Geological Survey Open-File Report 85-0645, 25 p.

Cunningham, J.E., 1974, Geologic map and sections of Silver City Quadrangle, New Mexico: New Mexico Bureau of Mines and Mineral Resources Geologic Map 30, scale 1:24,000.
Daggett, P.H., 1982, An integrated geophysical study of the crustal structure of the southern Rio Grande Rift: Las Cruces, New Mexico State University, unpublished Ph. D. dissertation, 208 p.
Daggett, P.H., Keller, G.R., and Morgan, P., 1981, Crustal structure studies in the southern Rio Grande Rift [abs.]: Earthquake Notes, v. 52, no. 1, p. 53.
Daggett, P.H., Keller, G.R., Morgan, Paul, and Wen, Cheng-Lee, 1986, Structure of the southern Rio Grande Rift from gravity interpretation: Journal of Geophysical Research,v. 91, no. B6, p. 6157-6167.
Dale, V.B., and McKinney, W.A., 1959, Tungsten deposits of New Mexico: U.S. Bureau of Mines Report of Investigations 5517, 72 p.
Damon, P.E., 1971, The relationship between late Cenozoic volcanism and tectonism and orogenic-epeirogenic periodicity, *in* The Late Cenozoic glacial ages: New Haven, Yale University Press, p. 15-35.
Damon, P.E., Shafiqullah, M., and Clark, K.F., 1981, Age trends of igneous activity in relation to metallogenesis in the southern Cordillera, *in* Dickinson, W.R., and Payne, W.D., eds., Relations of tectonics to ore deposits in the southern Cordillera: Arizona Geological Society Digest, v. 14, p. 137-154.
Dane, C.H., and Bachman, G.O., 1961a, Geologic map of New Mexico: U.S. Geological Survey State Geological Map Series, scale 1:500,000.
Dane, C.H., and Bachman, G.O., 1961b, Preliminary geologic map of the southwestern part of New Mexico: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-344, scale 1:380,160.
Dane, C.H., Wanek, A.A., and Reeside, J.B., Jr., 1957, Reinterpretation of section of Cretaceous rocks in Alamosa Creek Valley area, Catron and Socorro Counties, New Mexico: American Association of Petroleum Geologists Bulletin, v. 41, no. 2, p. 181–196.
Darton, N.H., 1916, Geology and underground water of Luna County, New Mexico: U.S. Geological Survey Bulletin 618, 188 p.
Darton, N.H., 1917a, Geologic Atlas of the U.S.; Deming folio: U.S. Geological Survey Folio 207.
Darton, N.H., 1917b, A comparison of Paleozoic sections in southern New Mexico: U.S. Geological Survey Professional Paper 108, p. 31-55.
Darton, N.H., 1922, Geologic structure of parts of New Mexico: U.S. Geological Survey Bulletin 726-E, p. 173-275.
Darton, N.H., 1925, Topographic and geologic maps of Arizona and New Mexico: Pan-American Geologist, v. 43, no. 5, p. 364.
Darton, N.H., and Burchard, E.F., 1911, Fluorspar near Deming, New Mexico: U.S. Geological Survey Bulletin 470, p. 533-545.
Dasch, M.D., 1965, Antimony, arsenic, bismuth, and cadmium; in Mineral and water resources of New Mexico: U.S. Congress, 89th, 1st session, Senate Committee on Interior and Insular Affairs: New Mexico Bureau of Mines and Mineral Resources Bulletin 87, p. 365-372.
Davie, W., and Spiegel, Z., 1967, Geology and water resources of Las Animas Creek and vicinity, Sierra County, New Mexico: New Mexico State Engineer, Santa Fe, Las Animas Creek Hydrographic Survey Report, 44 p.
Davis, G.H., 1978, Monocline fold pattern of the Colorado Plateau: Geological Society of America Memoir 151, p. 215-234.
Davis, G.H., 1979, Laramide folding and faulting in southeastern Arizona: American Journal of Science, v. 279, no. 5, p. 543-569.
Davis, Keith, 1986, An integrated geophysical study of the Knight Peak graben: Las Cruces, New Mexico State University, unpublished Master's thesis, 56 p.

Davis, Keith, Harder, S., Greensfelder, R.W., and Ni, J., 1988, An integrated geophysical study of the Knight Peak graben, *in* Mack, G.H., Lawton, T.F., and Lucas, S.G., eds., Cretaceous and Laramide tectonic evolution of southwestern New Mexico: New Mexico Geological Society, 39th annual field conference, Deming, N. Mex., p. 76-81.

Dawson, K.M., 1984, Skarn tungsten, *in* Eckstrand, O.R., ed., Canadian mineral deposit types --A geologic synopsis: Geological Survey of Canada Economic Geology Report 36, p. 55.

Dawson, K.M., and Snagster, D.F., 1984, Skarn zinc-lead-silver, *in* Eckstrand, O.R., ed., Canadian mineral deposit types --A geologic synopsis: Geological Survey of Canada Economic Geology Report 36, p. 56.

De, G.S., Winterstein, D.F., Meadows, M.A., 1994, Comparison of P- and S-wave velocities and Q's from VSP and sonic log data: Geophysics, v.59, no.10, p.1512-1529.

Deal, E.G., Elston, W.E., Erb, E.E., Peterson, S.L., Reiter, D.E., Damon, P.E., and Shafiqullah, M., 1978, Cenozoic volcanic geology of the Basin and Range province in Hidalgo County, southwestern New Mexico, *in* Callender, J.F., Wilt, J.C., and Clemons, R.E., eds., Land of Cochise, Southeastern Arizona: New Mexico Geological Society, *in cooperation with* Arizona Geological Society, 29th Field Conference, p. 219-229.

DeCicco, D.A., and Patterson, E.D., 1980a, Leasable mineral and waterpower land classification map of the Douglas quadrangle, Arizona, New Mexico: U.S. Geological Survey Open-File Report 80-0493.

DeCicco, D.A., and Patterson, E.D., 1980b, Leasable mineral and waterpower land classification map of the El Paso quadrangle, New Mexico, Texas: U.S. Geological Survey Open-File Report 80-0256.

DeCicco, D.A., and Patterson, E.D., 1980c, Leasable mineral and waterpower land classification map of the Las Cruces quadrangle, New Mexico, Texas: U.S. Geological Survey Open-File Report 80-0257.

DeCicco, D.A., and Patterson, E.D., 1980d, Leasable mineral and waterpower land classification map of the Clifton quadrangle, New Mexico and Arizona: U.S. Geological Survey Open-File Report 80-0254.

DeCicco, D.A., Patterson, E.D., and Morgan, R.D., 1980, Leasable mineral and waterpower land classification map of the Silver City quadrangle, New Mexico and Arizona: U.S. Geological Survey Open-File Report 80-0492.

Decker, E.R., Cook, F.A., Ramberg, I.B., and Smithson, S.B., 1975, Significance of geothermal and gravity studies in the Las Cruces area, *in* Seager, W.R., Clemons, R.E., and Callender, J.F., eds., Guidebook of the Las Cruces Country: New Mexico Geological Society, 26th Annual Field Conference, p. 251-259.

Decker, E.R., and Smithson, S.B., 1975, Heat flow and gravity interpretation in southern New Mexico and West Texas: Journal of Geophysical Research, v. 80, p. 2542-2552.

Deen, R.D., 1976, The mineralization in the Precambrian rocks of the Northern Franklin Mountains, *in* LeMone, D.V., and Lovejoy, E.M.P., eds., Symposium on the Franklin Mountains: El Paso Geological Society Quinn Memorial Volume, p. 183-188.

DeHon, R.A., 1965a, The Aden Crater lava cone: Compass, v. 43, p. 34-40.

DeHon, R.A., 1965b, Maare of La Mesa, *in* Fitzsimmons, J.P., and Lochman-Balk, Christina, eds., Guidebook of southwestern New Mexico II: New Mexico Geological Society, 16th Field Conference, p. 204-209.

Delaney, T.A., Day, G.W., Turner, R.L., and Jones, J.L., 1987, Analytical results and sample locality map of heavy-mineral-concentrate and rock samples from the Organ Mountains Wilderness study area (NM-030-074), Dona Ana County, New Mexico: U.S. Geological Survey Open-File Report 87-0638, 13 p., 1 sheet, scale 1:24,000, 5 tables.

Dellechaie, F., 1977, A geological and hydrochemical study of the Animas geothermal area, Hidalgo County, New Mexico: Geothermal Resources Council, Transactions, v. 1, p. 73-75.

DeMark, R.S., 1985, Minerals of the Alhambra Mine, Grant County, New Mexico [abs.]: New Mexico Geology, v. 7, no. 2, p. 41.
Denison, R.E., and Hetherington, E.A., 1969, Basement rocks in far west Texas and south-central New Mexico, *in* Kottlowski, F.E., and LeMone, D.V., eds., Border Stratigraphy Symposium: New Mexico Bureau of Mines and Mineral Resources Circular 104, p. 1-16.
Desborough, G.A., 1993, Ion-exchange of clinoptilolite-rich rocks in Argo drain water at Idaho Springs, Colorado, and related experimental aspects: U.S. Geological Survey Open-File Report 93-321, 23 p.
DeVaney, F.D., Fine, M.M., and Shelton, S.M., 1942, Manganese investigations-metallurgical division: U.S. Bureau of Mines Report of Investigations 3620, 9 p.
Dickinson, W.R., 1981, Plate tectonic evolution of the southern Cordillera; in Dickinson, W.R., and Payne, W.D., eds., Relations of tectonics to ore deposits in the southern Cordillera: Arizona Geological Society Digest, v. 14, p. 113-135.
Dickinson, W.R., 1989, Tectonic setting of Arizona through geologic time, *in* Jenney, J.P., and Reynolds, S.J., eds., Geologic evolution of Arizona: Tucson, Arizona Geological Society Digest 17, p. 1-16.
Dickinson, W.R., and Snyder, W.S., 1978, Plate tectonics of the Laramide orogeny: Geological Society of America Memoir 151, p. 355-365.
Diehl, J.F., McClannahan, K.M., and Bornhorst, T.J., 1988, Paleomagnetic results from the Mogollon-Datil volcanic field, southwestern New Mexico, and a refined mid-Tertiary reference pole for North America: Journal of Geophysical Research, v. 93, no. 5, p. 4869-4879.
Dikau, Richard, Brabb, E.E., and Mark, R.M., 1991, Landform classification of New Mexico by computer: U.S. Geological Survey Open-File Report 91-634, 2 plates, scale 1:1,000,000.
Diment, W.H., 1980, Resource characteristics: exploration evaluation and development, *in* Kestin, Joseph, DiPippo, Ronald, and Ryley, D.J., eds., Sourcebook on the production of electricity from geothermal energy: Washington D.C., U.S. Government Printing Office, p. 1-103.
Dinsmore, C.A., 1908, The new gold camp of Sylvanite, New Mexico: Mining World, v. 29, p. 670-671.
Dolton, G.L., Carson, K.H., Charpentier, R.R., Coury, A.B., Corvelli, R.A., Frezon, S.E., Khan, A.S., Lister, J.H., McMullin, R.H., Pike, R.S., Powers, R.B., Scott, E.W., and Varnes, K.L., 1981, Estimates of undiscovered recoverable conventional resources of oil and gas in the United States: U.S. Geological Survey Circular 860, 87 p.
Donnan, G.R., 1987, Stratigraphy and structural geology of the northern part of the northern Animas Mountains, Hidalgo County, New Mexico: Las Cruces, New Mexico State University, unpublished Master's thesis, 121 p.
Donnan, G.T., and Wilson, G.C., 1986, Reinterpretation of structural geology of northern Animas Mountains, Hidalgo County, New Mexico: American Association of Petroleum Geologists Bulletin, v. 70, p. 344.
Doraibabu, Peethambaram, 1971, Trace base metals, petrography, rock alteration of the productive Tres Hermanas stock, Luna County, New Mexico: Rolla, University of Missouri, Ph. D. dissertation, unknown p.
Doraibabu, Peethambaram, and Proctor, P.D., 1972, Zinc-lead-copper trace contents in Tres Hermanas stock, Luna County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Target Exploration Report E-4, 9 p.
Doraibabu, Peethambaram, and Proctor, P.D., 1973, Trace base metals, petrography, and alteration of the Tres Hermanas stock, Luna County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Geologic Map 132, 29 p.

Dorr, J.V.N., III, 1965, Manganese; in Mineral and water resources of New Mexico: U.S. Congress, 89th, 1st session, Senate Committee on Interior and Insular Affairs: New Mexico Bureau of Mines and Mineral Resources Bulletin 87, p. 183-195.

Doty, G.C., 1959, Mimbres Valley, Luna County, *in* Annual water level measurements in observation wells, 1951-1955, and atlas of maps showing changes of water levels for various periods from beginning of record through 1954: New Mexico State Engineer Technical Report no. 13, p. 299-339.

Doty, G.C., 1960, Reconnaissance of ground water in Playas Valley, Hidalgo County, New Mexico: New Mexico State Engineers Technical Report 15, 40 p.

Doty, G.C., and Cooper, J.B., 1970, Stratigraphic test well T-14, Post area, White Sands Missile Range, New Mexico: U.S. Geological Survey Open-File Report, 34 p.

Drake, P., Eberly, P., Renault, C., Royek, T., and Skirvin, T., 1988, Catenary soil development and slope degradation on three late Quaternary fault scarps in New Mexico [abs.]: New Mexico Geology, v. 11, no. 2, p. 41.

Drew, L.M., Bliss, J.D., Bowen, R.W., Bridges, N.J, Cox, D.P., DeYoung, J.H., Jr., Houghton, J.C., Ludington, S., Menzie, W.D., Page, N.J., Root, D.H., and Singer, D.A., 1986, Quantitative estimation of undiscovered mineral resources--A case study of U.S. Forest Service wilderness tracts in the Pacific Mountain System: Economic Geology, v. 81, no. 1, p. 80-88.

Drewes, H., 1968, The Laramide orogeny of Arizona southeast of Tucson [abs.]: Geological Society of America Abstracts with Programs, Cordilleran Section, 64th Annual Meeting, Tucson, p. 52-53.

Drewes, H.D., 1970, Structural control of geochemical anomalies in the Greaterville mining district, southeast of Tucson, Arizona: Contributions to economic geology; U. S. Geological Survey Bulletin, p. A1-A49.

Drewes, H.D., 1971, Mesozoic stratigraphy of the Santa Rita Mountains, southeast of Tucson, Arizona: U. S. Geological Survey Professional Paper 658-C, p. C1-C81.

Drewes, H.D., 1975, Tectonic development of southeastern Arizona in Mesozoic and Tertiary time [abs.]): Geological Society of America Abstracts with Programs, v. 7, no. 7, p. 1059.

Drewes, H.D., 1980, Tectonic map of southeast Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map I-1109, scale 1:24,000.

Drewes, H.D., 1981, Tectonics of southeastern Arizona: U.S. Geological Survey Professional Paper, 96 p.

Drewes, Harald, 1978, The Cordilleran orogenic belt between Nevada and Chihuahua: Geological Society of America Bulletin, v. 89, no. 5, 641-657.

Drewes, Harald, 1982, Northwest-trending basement flaws--A control to fluid movement and possible measure of rate of plate convergence, *in* Geologic Studies of the Cordilleran Thrust Belt: Rocky Mountain Association of Geologists, v. 1, p. 421-423.

Drewes, Harald, 1986, Geologic map of the northern part of the Animas Mountains, Hidalgo County, New Mexico: U.S. Geological Survey Miscellaneous Investigations Series Map I-1686, scale 1:24,000.

Drewes, 1987, Geologic map and cross sections of the Dragoon Mountains, southeastern Arizona: U.S. Geological Survey Miscellaneous Investigations Series I-1662, scale 1:24,000.

Drewes, Harald, 1989a, Description and development of the Cordilleran orogenic belt in the southwestern United States and northern Mexico: U.S. Geological Survey Professional Paper 1512, 92 p.

Drewes, Harald, 1989b, Development of the foreland zone of the Cordilleran orogenic belt near the U.S.-Mexican Border, *in* Schmidt, C.J., and Perry, W.J., Jr., eds., Interaction of the Rocky Mountain Foreland and the Cordilleran thrust belt: Geological Society of America Memoir 171, p. 447-463.

Drewes, Harald, 1989c, Summary, *in* Drewes, Harald, and Dyer, Russ, 1989, Tectonics of the eastern part of the Cordilleran Orogenic Belt, Chihuahua, New Mexico, and Arizona; Field Trip Guidebook T121, 28th International Geological Congress: American Geophysical Union, Washington, D.C., p. 1-3.

Drewes, Harald, 1991a, Geologic map of the Big Hatchet Mountains, Hidalgo County, New Mexico: U.S. Geological Survey Miscellaneous Investigations Series Map I-2144, scale 1:24,000.

Drewes, Harald, 1991b, Description and development of the Cordilleran orogenic belt in the Southwestern United States and northern Mexico: U.S. Geological Survey Professional Paper 1512, 92 p.

Drewes, Harald, Barton, H.N., Hanna, W.F., and Scott, D.C., 1988, Mineral resources of the Big Hatchet Mountains Wilderness Study Area, Hidalgo County, New Mexico: U.S. Geological Survey Bulletin 1735-C, 22 p.

Drewes, Harald, and Dyer, Russ, 1989, Tectonics of the eastern part of the Cordilleran Orogenic Belt, Chihuahua, New Mexico, and Arizona: Field Trip Guidebook T121, 28th International Geological Congress: American Geophysical Union, Washington, D.C., p. 1-3

Drewes, H.D., du Bray, E.A., and Pallister, J.S., 1995, Geologic map of the Portal quadrangle and vicinity, Cochise County, southeast Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map I–2450, scale 1:24,000.

Drewes, H.D., Houser, B.B., Hedlund, D.C., Richter, D.H., Thorman, C.H., and Finnell, T.L., 1985, Geologic map of the Silver City 1°x2° quadrangle, New Mexico and Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map I-1310-C.

Drewes, H.D., LeMone, D.V., Seager, W.R., Clemons, R.E., and Thompson, S., III, 1982, Styles of deformation in the southern Cordillera, U.S.A.--A transect of the Cordilleran orogenic belt from El Paso, Texas, to Wickenburg, Arizona, in Powers, R.B., ed., Geologic studies of the Cordilleran thrust belt: Denver, Colorado, Rocky Mountain Association of Geologists, p. 875–976.

Drewes, Harald, and Thorman, C.H., 1978, Major geologic structures between Lordsburg, New Mexico and Douglas and Tucson, Arizona, *in* Callender, J.F., Wilt, J.C., and Clemons, R.E., eds., Land of Cochise, Southeastern Arizona: New Mexico Geological Society *in cooperation with* Arizona Geological Society, 29th Annual Field Conference, p. 291-295.

Drewes, Harald, and Thorman, C.H., 1980a, Geologic map of the Cotton City quadrangle and the adjacent part of the Vanar quadrangle, Hidalgo County, New Mexico: U.S. Geological Survey Miscellaneous Investigations Series Map I-1221, scale 1:24,000.

Drewes, Harald, and Thorman, C.H., 1980b, Geologic map of the Steins and part of the Vanar quadrangles, New Mexico and Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map I-1220, scale 1:24,000.

Dromgoole, E.L., and Pasteris, J.D., 1987, Interpretation of the sulfide assemblages in a suite of xenoliths from Kilbourne Hole, New Mexico, *in* Morris, E.M., and Pasteris, J.D., eds., Mantle metasomatism and alkaline magmatism: Alpine, Texas, Sul Ross State University, Geological Society of America Special Paper 215, p. 25-46.

du Bray, E.A., and Pallister, J.S., 1991, An ash flow caldera in cross section--Ongoing field and geochemical studies of the mid-Tertiary Turkey Creek caldera, Chiricahua Mountains, SE Arizona: Journal of Geophysical Research, v. 96, no. B8, p. 13,435-13,437.

du Bray, E.A., and Pallister, J.S., 1992, Roadside geology of the central Chiricahua Mountains--A geologic synopsis of the Turkey Creek Caldera, *in* Barton, A.M., and Sloane, S.A., eds., Chiricahua Mountains Research Symposium, Pine Canyon United Methodist Camp, Chiricahua Mountains, Cochise County, Ariz., 16-17 March, 1992: Tucson, Ariz., Southwest Parks and Monuments Association, p. 9-12.

Duffield, W.A., 1987, Relations between cassiterite-bearing veins and rhyolite lavas, Black Range area, southwestern New Mexico [abs.], *in* Sachs, J.S., ed., USGS Research on Mineral Resources, 1987, Program and Abstracts: U.S. Geological Survey Circular 995, p. 16-17.

Duffield, W.A., Reed, B.L., and Richter, D.H., 1990, Origin of rhyolite-hosted tin mineralization--evidence from the Taylor Creek Rhyolite, New Mexico: Economic Geology, v. 85, no. 2, p. 392-398

Duffield, W.A., Sass, J.H., and Sorey, M.L., 1994, Tapping the Earth's Natural Heat: U.S. Geological Survey Circular 1125, 63p.

DuHamel, J.E., Cook, S.S., and Kolessar, J., 1995, Geology of the Tyrone porphyry copper deposit, New Mexico; *in* Pierce, F.W. and Bolm, J.G., eds., Porphyry copper deposits of the American Cordillera: Arizona Geological Society Digest 20, p. 464-472.

Dumas, F., 1974, Sample log; Grimm, Hunt, Brown and American Arctic Ltd., No. 1 Mobil-32 well, Doña Ana County, New Mexico: Permian Basin Sample Laboratory, Midland, Texas, unpublished document, unpaginated.

Dumble, E.T., 1902, Notes on the geology of southeastern Arizona: American Institute of Mining Engineers, trans. 31, p. 696-715.

Dunham, K.C., 1935, The geology of the Organ Mountains, with an account of Doña Ana County, New Mexico: New Mexico State Bureau of Mines and Mineral Resources Bulletin 11, 272 p.

Dunn, P.J., 1974, Chromian spinel inclusions in American peridots: Dtsch. Gemmol. Ges., Z. v. 23, no. 4, p. 304-307.

Dupree, J.A., and Eveleth, R.W., 1991, New Mexico: U.S. Bureau of Mines Annual Report, 16 p.

Duval, J.S., Jones, W.J., Riggle, F.R., and Pitkin, J.A., 1995, Potassium, uranium, and thorium aerial gamma-ray maps of the conterminous United States: U.S. Geological Survey Geophysical Investigations Map GP-nnnn, 3 maps, scale 1:2,500,000, 7 p. text.

Eaton, G.P., 1970, Preliminary aeromagnetic map of the Morenci-Monticello area, southeastern Arizona and southwestern New Mexico: U.S. Geological Survey Open-File Report.

Eaton, G.P., 1979a, Regional geophysics, Cenozoic tectonics, and geologic resources of the Basin and Range Province and adjoining regions, *in* Newman, G.W., and Goode, H.D., eds., Basin and Range Symposium and Great Basin Field Conference: Rocky Mountain Association of Geologists, p.11-39

Eaton, G.P., 1979b, A plate-tectonic model for late Cenozoic crustal spreading in the western United States, *in* Riecker, R.E., ed., Rio Grande rift--Tectonics and magmatism: American Geophysical Union, Washington, D.C., p. 7-32.

Eaton, G.P., 1981, Geologic resources of the regions of late Cenozoic rifting in western North America; papers presented to the Conference on the processes of planetary rifting: Lunar and Planetary Institute Contribution 457, p. 179-180.

Eaton, G.P., 1982, The Basin and Range Province--Origin and tectonic significance: Annual Reviews Earth Planetary Science, v. 10, p. 409-440.

Eaton, G.P., Peterson, D.L., and Webring, M.W., 1977, Bouguer gravity map of the Mogollon-Santa Rita-Tyrone region, southwestern New Mexico: U.S. Geological Survey Open-File Report 77-0650.

Eckstrand, O.R., ed., 1984, Canadian mineral deposit types: A geological synopsis: Geological Survey of Canada, Economic Geology Report 36, 86 p.

Eggleston, T.L., compiler, 1985, Epithermal deposits in New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 199, 55 p.

Eggleston, T.L., and Norman, D.I., 1983, Tin mineralization in Taylor Creek Rhyolite, Black Range, New Mexico [abs.]: New Mexico Geology, v. 5, no. 3, p. 66.

Eggleston, T.L., and Norman, D.I., 1987, New isotopic dates for the Taylor Creek Rhyolite and associated rocks in the Black Range of New Mexico: Isochron/West, no. 48, p. 23-25.

Eimon, P.I., and Bazrafshan, Khosrow, 1988, Hydrothermal modeling, Steeple Rock district, New Mexico [abs.]: New Mexico Geology, v. 11, no. 2, p. 43.
Einaudi, M.T., and Burt, D.M., 1982, Introduction, terminology, classification and composition of skarn deposits: Economic Geology, v. 77, no. 4, p. 745-754.
Einaudi, M.T., Meinert, L.D., and Newberry, R.S., 1981, Skarn deposits, *in* Skinner, B.J., ed., Seventy-Fifth Anniversary Volume, 1905-1980: Economic Geology Publishing Company, p. 317-391.
Elassal, A.A., and Caruso, V.M., 1983, Digital elevation models, USGS digital cartographic data standards: U.S. Geological Survey Circular 895-B, 40 p.
El Foul, D., 1976, Stratigraphy and microfacies analysis of the Bishop Cap Formation at Vinton Canyon, Franklin Mountains, El Paso County, Texas, *in* LeMone, D.V., and Lovejoy, E.M.P., eds., El Paso Geological Society symposium on the Franklin Mountains: p. 57-60.
El Paso Geological Society, 1973, Hoffer, J.M., ed., Hoffer, J.M., King, W.E., Kottlowski, F.E., and Strain, W.S., field trip leaders, The Geology of Southcentral Doña Ana County, New Mexico: Guidebook, Seventh Annual Field Trip of the El Paso Geological Society, Apr. 7, 1973, 67 p.
Ellis, R.D., 1971, Geology of the ore deposits of the Winkler Anticline, Hidalgo County, New Mexico: El Paso, University of Texas, unpublished Master's thesis, 76 p.
Ellis, R.W., 1930, New Mexico mineral deposits except fuels: Albuquerque, University of New Mexico Geological Series, v. 4, no. 2, Bulletin 167, 148 p.
Elston, W.E., 1956, Reconnaissance geology of the Virden quadrangle, Grant and Hidalgo Counties, New Mexico: Geological Society of America Bulletin, v. 67, no. 12, pt. 2, p. 1691-1692.
Elston, W.E., 1957, Geology and mineral resources of Dwyer quadrangle, Grant, Luna, and Sierra Counties, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 38, 86 p.
Elston, W.E., 1958, Burro uplift, northeastern limit of sedimentary basin of southwestern New Mexico and southeastern Arizona: American Association of Petroleum Geologists Bulletin, v. 42, no. 10, p. 2513-2517.
Elston, W.E., 1959, Some features of pyrometasomatic ore deposits in the Peloncillo Mountains, Hidalgo County, New Mexico: New Mexico Geological Society Guidebook, 10th Field Conference, p. 159-160.
Elston, W.E., 1960, Geology and mineral resources of Hidalgo County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Open-File Report, 448 p. (On file at the New Mexico Bureau of Mines and Mineral Resources, Socorro, N. Mex.)
Elston, W.E., 1960, Reconnaissance geologic map of Virden 30-minute quadrangle: New Mexico Bureau of Mines and Mineral Resources Geologic Map 15, scale 1:126,720.
Elston, W.E., 1961, Upper Cretaceous volcanism and mineralization in Steeple Rock mining district, Grant County, New Mexico [abs.] *in* Guidebook of the Albuquerque Country: New Mexico Geological Society Guidebook, 12th Annual Field Conference, p. 193.
Elston, W.E., 1964, Orogenesis and periods of mineralization in ten selected mining districts, southwestern New Mexico: Geological Society of America Special Paper 76, p. 272.
Elston, W.E., 1965a, Mining districts of Hidalgo County, New Mexico, *in* Fitzsimmons, J.P., and Lochman-Balk, Christina, eds., Guidebook of southwestern New Mexico II: New Mexico Geological Society, 16th Field Conference, p. 210-214.
Elston, W.E., 1965b, Volcanic rocks of the Mimbres and upper Gila drainages, New Mexico; *in* Fitzsimmons, J.P., and Lochman-Balk, Christina, eds., Guidebook of southwestern New Mexico II: New Mexico Geological Society, 16th Field Conference, p. 167-179.
Elston, W.E., 1965c, Rhyolite ash-flow plateaus, ring-dike complexes, calderas, lopoliths, and moon craters: Annals New York Academy of Sciences, v. 123, p. 817-842.
Elston, W.E., 1968, Terminology and distribution of ash flows of the Mogollon-Silver City-Lordsburg region, New Mexico: Arizona Geological Society Guidebook III to southern Arizona, p. 231-240.

Elston, W.E., 1970, Volcano-tectonic control of ore deposits, southwestern New Mexico, *in* Woodward, L.A., ed., Guidebook of the Tyrone-Big Hatchet Mountains-Florida Mountains Region: New Mexico Geological Society, 21st Annual Field Conference, p. 147-153.

Elston, W.E., 1973, Mid-Tertiary cauldrons and their relationship to mineral resources, southwestern New Mexico --A brief review; *in* Chapin, C.E., and Elston, W.E., eds., Field guide to selected cauldrons and mining districts of the Datil-Mogollon volcanic field, New Mexico: New Mexico Geological Society Special Publication No. 7, p. 107-113.

Elston, W.E., 1974, Some guides to mineralization in Hidalgo County, New Mexico: Silver Anniversary Guidebook, Ghost Ranch, central-northern New Mexico, Annual Field Conference Guidebook, no. 25, p. 378.

Elston, W.E., 1976, Glossary of stratigraphic terms of the Mogollon-Datil volcanic province, New Mexico: New Mexico Geological Society Special Publication 5, p. 131-145.

Elston, W.E., 1978, Mid-Tertiary cauldrons and their relationship to mineral resources, southwestern New Mexico--A brief review, *in* Chapin, C.E., Elston, W.E., and James, H.L., eds., Field guide to selected cauldrons and mining districts of the Datil-Mogollon volcanic field, New Mexico: New Mexico Geological Society Special Publication no. 7, p. 107-113.

Elston, W.E., 1981, Assessment of the geothermal potential of southwestern New Mexico: New Mexico Research and Development Institute, Report EMD 2-67-2123, 39 p.

Elston, W.E., 1983, Cenozoic volcanic centers in the New Mexico segment of the Pedregosa Basin; constraints on oil and gas exploration in southwestern New Mexico--Application of volcanology to petroleum exploration in southwestern New Mexico: Albuquerque, University of New Mexico report NMERDI 2-66-3104, 54 p.

Elston, W.E., 1984a, Mid-Tertiary ash flow tuff cauldrons, southwestern New Mexico: Journal of Geophysical Research, v. 89, no. 10, p. 8733-8750.

Elston, W.E., 1984b, Subduction of young oceanic lithosphere and extension orogeny in southwest North America during mid-Tertiary times: Tectonics, v. 3, p. 229-250.

Elston, W.E., 1989, Overview of the Mogollon-Datil volcanic field, *in* Chapin, C.E., and Zidek, Jiri, eds., Field excursions to volcanic terranes in the western United States, Volume I--Southern Rocky Mountain region: New Mexico Bureau of Mines and Mineral Resources Memoir 46, p. 43-46.

Elston, W.E., 1994, Siliceous volcanic centers as guides to mineral exploration --review and summary: Economic Geology, v. 89, no. 8, p. 1662-1686.

Elston, W.E., Bikerman, Michael, and Damon, P.E., 1968, Significance of new K-Ar dates from southwestern New Mexico, *in* Correlation and chronology of ore deposits and volcanic rocks: University of Arizona Annual Progress Report C00-689-100, to Research Division, U.S. Atomic Energy Commission, p. A1-A20.

Elston, W.E., and Bornhorst, T.J., 1979, The Rio Grande rift in context of regional post-40 m.y. volcanic and tectonic events, *in* Riecker, R.E., ed., Rio Grande Rift--Tectonics and Magmatism: Washington, D.C., American Geophysical Union, p. 416-438.

Elston, W.E., Coney, P.J., and Rhodes, R.C., 1970, Progress report on the Mogollon Plateau Volcanic Province, Southwestern New Mexico, no. 2; *in* Woodward, L.A., ed., Guidebook of the Tyrone-Big Hatchet Mountains-Florida Mountains Region: New Mexico Geological Society, 21st Annual Field Conference, p. 75-86. (also Colorado School of Mines Quarterly, v. 63, no. 3, p. 261-287.

Elston, W.E., Damon, P.E., Coney, P.J., Rhodes, R.C., Smith, E.I., and Bikerman, M., 1973, Tertiary volcanic rocks, Mogollon-Datil province, New Mexico, and surrounding region; K-Ar dates, patterns of eruption, and periods of mineralization: Geological Society of America Bulletin, v. 84, p. 2259-2274.

Elston, W.E., Deal, E.G., and Logsdon, M.J., 1983, Geology and geothermal waters of Lightning Dock region, Animas Valley and Pyramid Mountains, Hidalgo County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 177, 44 p., map scale 1:48,000.

Elston, W.E., and Erb, E.E., 1977, Cenozoic volcano-tectonic setting of KCM No. 1 Forest Federal Well, Animas Mountains, Hidalgo County, New Mexico, *in* Thompson, Sam, III, compiler, Geology, petroleum source rocks, and thermal metamorphism in KCM No. 1 Forest Federal well, Hidalgo County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 152, p. 53-62.

Elston, W.E., Erb, E.E., and Deal, E.G., 1979, Tertiary geology of Hidalgo County, New Mexico; guide to metals, industrial minerals, petroleum, and geothermal resources: New Mexico Geology, v. 1, no. 1, p. 1-6.

Elston, W.E., Farris, S.R., Krier, D.J., Seager, W.R., and Swanberg, C.A., 1981, Assessment of the geothermal potential of southwestern New Mexico: New Mexico Research and Development Institute, Report EMD 2-67-2123, 39 p.

Elston, W.E., and Netelbeek, T.A., 1965, Road log from Mimbres Valley to Silver City; *in* Fitzsimmons, J.P., and Lochman-Balk, Christina, eds., Guidebook of southwestern New Mexico II: New Mexico Geological Society, 16th Field Conference, p. 31-35.

Elston, W.E., Rhodes, R.C., Coney, P.J., and Deal, E.G., 1976a, Progress report on the Mogollon Plateau volcanic field southwestern New Mexico, no. 3--Surface expression of a pluton, *in* Elston, W.E., and Northrop, S.A., eds., Cenozoic volcanism in southwestern New Mexico: New Mexico Geological Society Special Publication No. 5, p. 3-28.

Elston, W.E., Rhodes, R.C., and Erb, E.E., 1976b, Control of mineralization by mid-Tertiary volcanic centers, southwestern New Mexico, *in* Elston, W.E., and Northrup, S.A., eds., Cenozoic volcanism in southwestern New Mexico: New Mexico Geological Society Special Publication 5, p. 125-130.

Elston, W. E., Rhodes, R.C., Coney, P.J., and Deal, E. G., 1976, Progress report on the Mogollon Plateau volcanic field, southwestern New Mexico, no. 3--Surface expression of a pluton, in Elston, W.E., and Northrup, S.A., eds., Cenozoic volcanism in southwestern New Mexico: New Mexico Geological Society, Special Publication 5, p. 3-28.

Elston, W.E., Seager, W.R., and Clemons, R.E., 1975, Emory Cauldron, Black Range, New Mexico--Source of Kneeling Nun Tuff, *in* Seager, W.R., Clemons, R.E., and Callender, J.F., eds., Guidebook of the Las Cruces Country: New Mexico Geological Society, 26th Annual Field Conference, p. 283-292.

Elston, W.E., Weber, R.H., and Trauger, F.D., 1965, Road log from Silver City to junction of New Mexico Highways 61 and 90, *in* Fitzsimmons, J.P., and Lochman-Balk, Christina, eds., Guidebook of southwestern New Mexico II: New Mexico Geological Society, 16th Field Conference, p. 45-62.

Emanuel, K.M., 1985, Geronimo project report: Nicor Mineral Ventures, Inc., unpublished report on file at New Mexico Bureau of Mines and Mineral Resources, Socorro, N. Mex.,, January 18, 1985, 30 p.

Emery, J.V., and Irving, A.J., 1988, Silicate glasses in mantle xenoliths; products of AFC reactions resulting from infiltration of basalt into mantle peridotite [abs.]: AGU 1988 fall meeting; EOS, Transactions, American Geophysical Union, v. 69, no. 44, p. 1490.

Emory, W.H., 1857, Report of the United States and Mexican boundary survey: U.S. 34th Congress, 1st session, Senate executive document 108, v. 1, pt. 2, 174 p.

Enders, M.S., 1981, The geology, mineralization, and exploration characteristics of the Beck mine and vicinity, Kimball mining district, Hidalgo County, New Mexico and Cochise County, Arizona: Tucson, University of Arizona Master's thesis, 109 p.

Entwistle, L.P., 1938, The Chloride Flat mining district, New Mexico: M.S. thesis, Tucson, University of Arizona, 92 pp.
Entwistle, L.P., 1944, Manganiferous iron-ore deposits near Silver City, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 19, 70 p.
Epis, R.C., and Chapin, C.E., 1975, Geomorphic and tectonic implications of the post-Laramide, Late Eocene erosion surface in the southern Rocky Mountains, *in* Curtis, B.F., Cenozoic history of the southern Rocky Mountains: Geological Society of America Memoir 144, p. 45-74.
Erb, E.E., 1979, Petrologic and structural evolution of ash-flow tuff cauldrons and noncauldron related volcanic rocks in the Animas and southern Peloncillo Mountains, Hidalgo Co., New Mexico: Albuquerque, University of New Mexico, Ph. D. dissertation, 286 p.
Ericksen, G.E., and Leland, G.R., 1984, Black Range Primitive Area, New Mexico, *in* Marsh, S.P., Kropschot, S.J., and Dickinson, R.G., eds., Wilderness mineral potential; Assessment of mineral resource potential in U.S. Forest Service lands studied 1964-1984: U.S. Geological Survey Professional Paper 1300, p. 795-797.
Ericksen, G.E., and Wedow, H., Jr., 1976, Tertiary extrusive sheets and related intrusions in the Black Range, New Mexico, *in* Elston, W.E., and Northrup, S.A., eds., Cenozoic volcanism in southwestern New Mexico: New Mexico Geological Society Special Publication 5, p. 63-67.
Ericksen, G.E., Wedow, Helmuth, Jr., and Eaton, G.P., U.S. Geological Survey *and by* Leland, G.R., U.S. Bureau of Mines, 1970, Mineral resources of the Black Range Primitive Area, Grant, Sierra, and Catron Counties, New Mexico: U.S. Geological Survey Bulletin 1319-E, 162 p., 2 plates (aeromagnetic and geologic map; geochemical sampling map), scale 1;63,360.
Ernst, W.G., compiler, 1991, Preliminary metamorphic map of the Western Conterminous U.S., Plate 9, The Cordilleran Orogen; Conterminous U.S., Geology of North America: Geological Society of America DNAG Vol. G-3, scale 1:5,000,000,000.
Evans, K.V., and Clemons, R.E., 1987, U-Pb geochronology of the Florida Mountains, New Mexico; new evidence for latest Cambrian-earliest Ordovician alkalic plutonism [abs.]: Geological Society of America Abstracts with Programs, v. 19, no. 7, p. 657-658.
Evans, K.V., and Clemons, R.E., 1988, Cambrian-Ordovician (500 Ma) alkalic plutonism in southwestern New Mexico; U-Th-Pb isotopic data from the Florida Mountains: American Journal of Science, v. 288, no. 7, p. 735-755.
Eveleth, R.W., 1983, An historical vignette--Stephenson-Bennett mine: New Mexico Geology, v. 5, no. 1, p. 9-13, 15.
Eveleth, R.W., and North, R.M., 1981, Report on the Battleship Group of patented mining claims, Lordsburg Mining District, Hidalgo County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Open File Report 166, unpaginated.
Everett, F.D., 1964, Reconnaissance of tellurium resources in Arizona, Colorado, New Mexico, and Utah--Including selected data from other western states and Mexico: U.S. Bureau of Mines Report of Investigations, no. 6350, 38 p.
Everhart, D.L., 1957, Uranium-bearing veins in the U.S., *in* Contributions to the geology of uranium and thorium: U.S. Geological Survey Professional Paper 300, p. 97-104.
Eyde, T.H., 1982, Zeolite deposits in the Gila and San Simon valleys of Arizona and New Mexico, *in* Austin, G.S., compiler, Industrial rocks and minerals of the southwest: New Mexico Bureau of Mines and Mineral Resources Circular 182, p. 65-71.
Farnham, L.L., 1961, Manganese deposits of New Mexico: U.S. Bureau of Mines Information Circular 8030, 176 p.
Farnham, L.L., Stewart, L.A. and DeLong, C.W., 1961, Manganese deposits of eastern Arizona: U.S. Bureau of Mines Information Circular 7990, 178 p.

Farris, S.R., 1981, Geology and mid-Tertiary volcanism of the McKnight Canyon area, Black Range, Grant County, New Mexico: Albuquerque, University of New Mexico, unpublished Master's thesis, 87 p.
Fassett, J.E., and Jentgen, R., 1978a, Largo Gallup (gas), *in* Fassett, J.E., and Thomaidis, N.D., Oil and gas fields of the Four Corners area: Four Corners Geological Society, Colo., p. 376–380.
Fassett, J.E., and Jentgen, R., 1978b, Tapacito Gallup (oil), *in* Fassett, J.E., and Thomaidis, N.D., Oil and gas fields of the Four Corners area: Four Corners Geological Society, Colo., p. 510–515.
Feingenson, M.D., 1986, Continental alkali basalts as mixtures of kimberlite and depleted mantle; evidence from Kilbourne Hole maar, New Mexico: Geophysical Research Letters, v. 13, no. 9, p. 965-968.
Ferguson, H.G., 1927, Geology and ore deposits of the Mogollon mining district, New Mexico: U.S. Geological Survey Bulletin 787, 100 p.
File, Lucien, and Northrop, S. A., 1966, County, township, and range locations of New Mexico's mining districts: New Mexico Bureau of Mines and Mineral Resources Circular 84, 66 p.
Filsinger, B., 1988, Geology and genesis of the Palm Park and Horseshoe barite deposits, southern Caballo Mountains, Dona Ana County, New Mexico: El Paso, University of Texas, unpublished Master's thesis, 250 p.
Finch, W.I., 1988, ed., Principal reference section fo the Santa Rosa Formation of Middle and Late Triassic age, Guadalupe County, New Mexico: U.S. Geological Survey Bulletin 1804, 25 p.
Finnell, T.L., 1970, Formations of the Bisbee Group, Empire Mountains Quadrangle, Pima County, Arizona; Changes in stratigraphic nomenclature by the U.S. Geological Survey: U.S. Geological Survey Bulletin 1294-A, p. A28-A35.
Finnell, T.L., 1976, Geologic map of the Twin Sisters quadrangle, Grant County, New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map MF-779.
Finnell, T.L., 1987, Geologic map of the Cliff quadrangle, Grant County, New Mexico: U.S. Geological Survey Miscellaneous Investigations Series Map I-1768.
Fischer, C.L., Whittier, J., Witcher, J.C., and Schoenmackers, R., 1990, An economic evaluation of southern New Mexico's low-temperature geothermal resources, *in* Combs, J., ed., Transactions, 1990 International symposium on geothermal energy: Davis, CA, Geothermal Resources Council, Transactions Geothermal Resources Council, v. 14, nos. 1-2, p. 495-498.
Fitzpatrick, D.P., McCurry, M., and Seager, W.R., 1988, The stratigraphy of the Cueva Tuff, part of a major intracaldera ash-flow tuff within the late Oligocene Organ Cauldron, southern New Mexico [abs.]: Geological Society of America Abstracts with Programs, v. 20, no. 3, p. 160.
Fitzsimmons, J.P., and Kelly, V.C., 1980, Red Rock talc deposit, Sierra County, New Mexico: New Mexico Geology, v. 2, p. 36-38.
Fitzsimmons, J.P., and Lochman-Balk, Christina, eds., 1965, Guidebook of southwestern New Mexico II: New Mexico Geological Society, Sixteenth Field Conference, 244 p.
Fix, J.E., 1973, Theoretical and observed noise in a high-sensitivity long-period seismograph: Seismological Society of America Bulletin, v. 63, no. 6, part 1, p. 1979-1998.
Flawn, P.T., 1954a, Summary of southeast New Mexico basement rocks: New Mexico Geological Society, 5th Field Conference, p. 114-116.
Flawn, P.T., 1954b, Texas basement rocks; a progress report: American Association of Petroleum Geologists Bulletin, v. 38, p. 900-912.
Flege, R.F., Jr., 1959, Geology of Lordsburg quadrangle, Hidalgo County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 62, 36 p. [Also Master's thesis, St. Louis, MO, Washington University, 1956].
Fleischhauer, H.L., 1978, Summary of the late Quaternary geology of Lake Animas, Hidalgo County, New Mexico, *in* Callender, J.F., Wilt, J.C., and Clemons, R.E., eds., Land of Cochise, Southeastern Arizona: New Mexico Geological Society, 29th Field Conference, 283-284.

Fleischhauer, H.L., Jr., and Stone, W.J., 1982, Quaternary geology of Lake Animas, Hidalgo County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 174, 25 p.

Flih, Baghdad, 1976a, Osagian bioherms at the Bishop Cap hills, Doña Ana County, New Mexico: El Paso, University of Texas, unpublished Master's thesis, 106 p.

Flih, Baghdad, 1976b, Stratigraphy and preliminary microfacies studies of the Osage (Mississippian) bioherms of the Lake Valley Formation, Bishop Cap Hills, Doña Ana County, New Mexico, *in* LeMone, D.V., and Lovejoy, E.M.P., Symposium on the Franklin Mountains: El Paso Geological Society Quinn Memorial Volume, p. 35-44.

Flower, R.H., 1953a, Age of Bliss Sandstone: American Association of Petroleum Geologists Bulletin, v. 37, p. 2054-2055.

Flower, R.H., 1953b, Paleozoic sedimentary rocks of southwestern New Mexico, *in* Kottlowski, F.E., ed., Southwestern New Mexico: New Mexico Geological Society, 4th Annual Field Conference, Guidebook, p. 106-112.

Flower, R.H., 1955, Pre-Pennsylvanian stratigraphy of southern New Mexico, *in* Fitzsimmons, J.P., ed., South-central New Mexico: New Mexico Geological Society, *in cooperation with* the Roswell Geological Society, 6th Annual Field Conference, p. 65-70.

Flower, R.H., 1959, Cambrian-Devonian beds of southern New Mexico: Roswell Geological Society and Permian Basin Section, Society of Economic Paleontologists and Mineralogists Guidebook, Sacramento Mountains, p. 154-171.

Flower, R.H., 1965, Early Paleozoic of New Mexico, *in* Fitzsimmons, J.P., and Lochman-Balk, Christina, eds., Guidebook of southwestern New Mexico II: New Mexico Geological Society, 16th Annual Field Conference, p. 61-78.

Fodor, R.V., 1975, Petrology of basalt and andesite of the Black Range, New Mexico: Geological Society of America Bulletin, v, 86, p. 295-304.

Fodor, R.V., 1978, Ultramafic and mafic inclusions and megacrysts in Pliocene basalt, Black Range, New Mexico: Geological Society of America Bulletin, v. 89, no. 3, p. 451-459.

Forrester, J.D., 1972, Skarn formation and sulfide mineralization at the Continental Mine, Fierro, New Mexico: Ithaca, N.Y., Cornell University, unpublished Ph. D. dissertation, 204 p.

Forsberg, R., and Tscherning, C.C., 1981, The use of height data in gravity field approximation by collocation: Journal of Geophysical Research, v. 86, no. 9, p. 7843-7854.

Foshag, W.F., and Fries, Carl, Jr., 1942, Tin deposits of the Republic of Mexico: U.S. Geological Survey Bulletin, 935-C, p. 99-176.

Foster, R.W., 1978, Selected data for deep drill holes along Rio Grande Rift in New Mexico, *in* Hawley, J.W., compiler, Guidebook to the Rio Grande rift in New Mexico and Colorado: Socorro, New Mexico Bureau of Mines and Mineral Resources Circular 163, p. 236-237.

Foster, R.W., and Grant, P.R., 1974, The future of New Mexico's oil and gas reserves: New Mexico Bureau of Mines and Mineral Resources Map 3, scale 1:585,000.

Foster, R.W., Gutjahr, A.L., and Warner, G.H., 1978, Estimates of New Mexico's future oil production, including reserves of the 50 largest pools: New Mexico Bureau of Mines and Mineral Resources Circular 166, 56 p.

Foster, R.W., and Stipp, T.F., 1961, Preliminary geologic and relief map of the Precambrian rocks of New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 57, 37 p.

Fox, J.S., 1984, Besshi-type volcanogenic sulfide deposits--a review: CIM (Canadian Institute of Mining and Metallurgy) Bulletin, v. 77, no. 864, p. 57-68.

Fox, W.J., 1975, The Broad Canyon Dam, *in* Seager, W.R., Clemons, R.E., and Callender, J.F., eds., Guidebook of the Las Cruces Country: New Mexico Geological Society, 26th Annual Field Conference, p. 181.

Franklin, J., Lydon, J.W., and Sangster, D.F., 1981, Volcanogenic massive sulfide deposits, *in* Skinner, B.F., ed., Economic Geology, Seventy-Fifth Anniversary Volume, 1905-1980: Economic Geology Publishing Company, p. 485-627.

Frantes, T.J., 1981, The geology of the Palomas Volcanic Field, Luna County, New Mexico and Chihuahua, Mexico: El Paso, University of Texas, unpublished Master's thesis, 70 p.

Frantes, T.J., and Hoffer, J.M., 1982, Palomas volcanic field, southern New Mexico and northern Chihuahua, Mexico: New Mexico Geology, v. 4, no. 1, p. 6-8, 16.

Fries, Carl, Jr., 1940, Tin deposits of the Black Range, Catron and Sierra Counties, New Mexico--A preliminary report [abs.]: American Geophysical Union Transactions, 21st annual meeting, pt. 1, p. 362.

Fries, Carl, Jr., and Butler, A.P., 1940, Geologic map of the Black Range tin district, New Mexico: U.S. Geological Survey Strategic Minerals Investigations Preliminary Map, scale 1:62,500.

Friesen, R.L., and Haneberg, W.C., 1992, Digital documentation of deformation and groundwater levels near an earth fissure in the Mimbres Basin, New Mexico [abs.]: New Mexico Geological Society Proceedings Volume, 1992 Annual Spring Meeting, p. 19. (also New Mexico Geology, v. 14, no. 3, p. 63.]

Fuhrbach, J.R., 1990, Kilbourne Hole maar peridot, Doña Ana County, New Mexico: 11th Annual New Mexico Mineral Symposium Proceedings, p. 9.

Fulp, M.S., 1987, Proterozoic tungsten mineralization of the southern Sangre de Cristo Mountains, New Mexico [abs.]: Geological Society of America Abstracts with Programs, v. 19, no. 7, p. 670.

Fulton, R.B., and Montgomery, G., 1994, Fluorspar, *in* Carr, D.D., ed., Industrial Minerals and Rocks: Littleton, Colorado, Society for Mining, Metallurgy, and Exploration, Inc., 6th edition, p. 509-522.

Funderberg, D.E., and Roybal, F.E., 1977, Sediment trap efficiency of Tortugas Arroyo near Las Cruces, New Mexico: U.S. Geological Survey Open-File Report 77-0586, 63 p.

Futa, K., and Ratté, J.C., 1989, Petrogenetic implications of Rb-Sr and Sm-Nd isotopes related to post-caldera volcanism in the western Mogollon-Datil volcanic field, New Mexico [abs.], *in* Barker, C.E., and Coury, A.B., eds., Abstracts of the U.S. Geological Survey, central region, 1989 poster review--Collected abstracts of selected poster papers presented at scientific meetings: U.S. Geological Survey Open-File Report 89-0644, p. 17.

Gallaher, B.M., and Gulf Mineral Resources Company, 1980, Pre-hearing ground water discharge plan analysis for Mt. Taylor uranium mill project, Gulf Mineral Resources Company: Santa Fe, New Mexico Health and Environment Department Report, *in cooperation with* U.S. Geological Survey.

Galusha, T., and Blick, J.C., 1971, Stratigraphy of the Santa Fe Group, New Mexico: American Museum of Natural History Bulletin, v. 144, article 1, 127 p.

Garcia, R.A., 1970, Geology and petrology of andesitic intrusions in and near El Paso, Texas: El Paso, University of Texas, unpublished Master's thesis, 139 p.

Garza, S., and McLean, J.S., 1977, Fresh-water resources in the southeastern part of the Tularosa Basin: New Mexico State Engineers, Technical Report 40, 67 p.

Gates, E.E., 1985, The geology of the Carrizalillo Hills, Luna County, New Mexico: El Paso, University of Texas, unpublished Master's thesis, 133 p., scale 1:12,000.

Gates, J.S., White, D.E., and Leggat, E.R., 1984, Preliminary study of the aquifers of the lower Mesilla Valley in Texas and New Mexico by model simulation: U.S. Geological Survey Water Resources Investigations 84-4317, 24 p.

Gates, J.S., White, D.E., Stanley, W.D., and Ackermann, Hans D., 1978, Availability of fresh and slightly saline ground in the basins of westernmost Texas: U.S. Geological Survey Open-File Report 78-663, 173 p.

Gebben, D.J., 1978, Geology of the central Peloncillo Mountains, the north third of the Pratt quadrangle, Hidalgo County, New Mexico: Kalamazoo,Western Michigan University, Master's thesis, 126 p.

Geeslin, J.H., 1980, Petrography of the Aleman Formation, Upper Ordovician, Silver City Range, southwestern New Mexico: Houston, Tex., University of Houston, unpublished Master's thesis, unknown p.
Geissman, J.W., Jackson, M., Harlan, S.S., and Van der Voo, R., 1991, Paleomagnetism of latest Cambrian-Early Ordovician and latest Cretaceous-early Tertiary rocks of the Florida Mountains, southwest New Mexico: Journal of Geophysical Research, v. 96, no. 4, p. 6053-6071.
Geitgey, R. P., 1994, Pumice and volcanic cinder, *in* Carr, D.D., ed., Industrial minerals and rocks: Littleton, Colorado,Society for Mining, Metallurgy, and Exploration, Inc., p. 803–813.
GeoChem Laboratories, 1976, Hydrocarbon source rock evaluation study; organic geochemical analyses of canned cuttings, KCM no. 1 Cochise-State A well, Hidalgo County, New Mexico: Prepared for New Mexico Bureau of Mines and Mineral Resources, New Mexico Bureau of Mines and Mineral Resources Open File Report 96, 22 p.
Geodata International, Inc., 1979, Aerial radiometric and magnetic survey, Tularosa national topographic map, New Mexico: U.S. Department of Energy, Grand Junction Office Report GJBX-67(79), 2 vols.
Gerwe, J.E., 1986, Ag-Ni-Co-As-U mineralization in the Black Hawk Mining District, Grant County, New Mexico: Socorro, New Mexico Institute of Mining and Technology, unpublished Master's thesis, 85 p.
Gerwe, J.E., and Norman, D.I., 1985, Ag-Ni-Co-U mineralization in the Black Hawk mining district, Grant County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 199, p. 52.
Gese, D.D., 1985, Mineral resources of the West Potrillo Mountains/Mt. Riley (NM-030-052) Study Area and the Aden Lava Flow (NM-030-053) Wilderness Study Area, Doña Ana and Luna Counties, New Mexico: U.S. Bureau of Mines Open File Report MLA 78-85, 19 p.
Giancola, D., ed., 1994, American Mines Handbook: Southern Magazine and Information Group, British Columbia, Canada, 376 p.
Gibbs, R.B., 1986, Phosphate mineralization at the Tyrone Mine, Grant County, New Mexico [abs.]: 7th Annual New Mexico Mineral Symposium, Proceedings, p. 13.
Gibbs, R.B., 1990, Phosphate occurrences in southwestern New Mexico: 11th Annual New Mexico Mineral Symposium, Proceedings, p. 10.
Gibson, W. A., and Trujillo, A. D., 1966, From Indian scrapings to 85-ton trucks--The development of Chino: Mining Engineering, v. 18, no. 1, p. 54-60.
Gilbert, G.K., 1875, Report on the geology of portions of New Mexico and Arizona: Publications of the Wheeler Survey, U. S. Geographic Survey, West 100th Meridian, no. 3, p. 503-567.
Gile, L.H., 1967, Soils of an ancient basin floor near Las Cruces, New Mexico: Soil Science, v. 103, p. 265-276.
Gile, L.H., 1970, Soils of the Rio Grande valley border in southern New Mexico: Soil Science Society of America, Proceedings, v. 34, no. 3, p. 465-472.
Gile, L.H., 1977, Holocene soils and soil-geomorphic relations in a semi-arid region of southern New Mexico: Quaternary Research, 7, no. 1, p. 112-132.
Gile, L.H., 1986, Late Holocene displacement along the Organ Mountains fault in southern New Mexico--A summary: New Mexico Geology, v. 8, no. 1, p. 1-4.
Gile, L.H., 1987a, Late Holocene displacement along the Organ Mountains fault in southern New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 196, 43 p.
Gile, L.H., 1987b, A pedogenic chronology for Kilburne Hole, southern New Mexico; II-- Time of the explosions and soil events before the explosions: Soil Science Society of America Journal, v. 51, no. 3, p. 746-760.
Gile, L.H., 1990, Chronology of lava and associated soils near San Miguel, New Mexico: Quaternary Research, v. 33, no. 1, p. 37-50.

Gile, L.H., Hawley, J.W., and Grossman, R.B., 1970, Distribution and genesis of soils and geomorphic surfaces in a desert region of southern New Mexico: Soil-geomorphology field conference, 155 p.
Gile, L.H., Hawley, J.W., and Grossman, R.B., 1981, Soils and geomorphology in the Basin and Range Area of southern New Mexico--Guidebook to the Desert Project: New Mexico Bureau of Mines and Mineral Resources Memoir 39, 222 p.
Gillerman, Elliot, 1952, Fluorspar deposits of the Burro Mountains and vicinity: U.S. Geological Survey Bulletin 973-F, p. 261-289.
Gillerman, E., 1953, White Signal uranium deposits; *in* Kottlowski, F. E., ed., Southwestern New Mexico: New Mexico Geological Society, Guidebook 4, pp. 133–137.
Gillerman, Elliot, 1958, Geology of the central Peloncillo Mountains, Hidalgo County, New Mexico, and Cochise County, Arizona: New Mexico Bureau of Mines and Mineral Resources Bulletin 57, 152 p.
Gillerman, E., 1959, The Alhambra mine, Black Hawk (Bullard's Peak) district, New Mexico: Mining Engineering, v. 11, no. 1, p. 44.
Gillerman, Elliot, 1964, Mineral deposits of western Grant County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 83, 213 p.
Gillerman, Elliot, 1967, Structural framework and character of mineralization, Burro Mountains, New Mexico: Economic Geology, v. 62, p. 370-375.
Gillerman, Elliot, 1968, Uranium mineralization in the Burro Mountains, New Mexico: Economic Geology, v. 63, no. 3, p. 239-246.
Gillerman, Elliot, 1970, Mineral deposits and structural pattern of the Big Burro Mountains, New Mexico, *in* Woodward, L.A., ed., Guidebook of the Tyrone-Big Hatchet Mountains-Florida Mountains Region: New Mexico Geological Society, 21st Annual Field Conference, p. 115-121.
Gillerman, Elliot, and Whitebread, D.H., 1956, Uranium-bearing nickel-cobalt-native silver deposits, Black Hawk District, Grant County, New Mexico: U.S. Geological Survey Bulletin 1009-K, 283-311.
Gilluly, 1945, Emplacement of the Uncle Sam porphyry, Tombstone, Arizona: American Journal of Science, v. 243, no. 12, p. 643-666.
Gilluly, 1956, General geology of central Cochise County, Arizona, *with sections on* age and correlation by Palmer, A.R., Williams, J.S., and Reeside, J.B., Jr.: U.S. Geological Survey Professional Paper 281, 169 p.
Gilluly, James, 1976, Lineaments--ineffective guides to ore deposits: Economic Geology, v. 71, no. 8, p. 1507-1514.
Gilluly, James, Cooper, J.R., and Williams, J.S., 1954, Late Paleozoic stratigraphy of central Cochise County, Arizona: U.S. Geological Survey Professional Paper 266, 49 p.
Gish, D.M., Keller, G.R., and Sbar, M.L., 1981, A refraction study of deep crustal structure in the Basin and Range; Colorado Plateau of eastern Arizona: Journal of Geophysical Research-B, v. 86, no. 7, p. 6029-6038.
Givens, D.B., 1951, A new basic copper phosphate mineral (chinoite) from Santa Rita, New Mexico: Albuquerque, University of New Mexico, unpublished Master's thesis, unknown p.
Givens, D.B., 1957, Geology of Dog Springs quadrangle, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 58, 40 p.
Glover, T.J., 1975, Geology and ore deposits of the northwestern Organ Mountains, Doña Ana County, New Mexico: El Paso, University of Texas, unpublished Master's thesis, 93 p.
Godson, R.H., and Plouff, Donald, 1988, Bouguer version 1.0: A microcomputer gravity-terrain-correction program: U.S. Geological Survey Open-File Report 88-644A-B, 15 p., 1 diskette.
Goetz, L.K., and Dickerson, P.W., 1985, A Paleozoic transform margin in Arizona, New Mexico, west Texas and northern Mexico, *in* Dickerson, P.W., and Muehlberger, W.R., eds., Structure and

tectonics of trans-Pecos Texas: West Texas Geological Society Field Conference, Publication 85-81, 173-184.
Goodell, P.C., 1976, Mineral occurrences of the Franklin Mountains, Texas; in LeMone, D.V. and Lovejoy, E.M.P., eds., Symposium on the Franklin Mountains: El Paso Geological Society, Quinn Memorial Volume, p. 189-200.
Goodell, P.C., 1987, Mineral occurrences of the Franklin Mountains, Texas, in LeMone, D.V., and Lovejoy, E.M.P., El Paso Geological Society symposium on the Franklin Mountains: El Paso Geological Society no. 10, Quinn volume, , p. 189-200.
Gordon, C.H., 1907, Mississippian (Lower Carboniferous) formations in the Rio Grande Valley, New Mexico: American Journal of Science, v. 4, no. 24, p. 58-64.
Gordon, C.H., and Graton, L.C., 1906, Lower Paleozoic formations in New Mexico: American Journal of Science, v. 4, no. 21, p. 390–395.
Gottardi, Glauco, and Galli, Ermanno, 1985, Natural zeolites: New York, Springer-Verlag, 409 p.
Graeme, D.L., and Graeme, R.W., IV, 1983a, The Philadelphia Mine [abs.]: New Mexico Geology, v. 5, no. 4, p. 84.
Graeme, R.W., IV, 1983, Chalcophanite from the Hanover-Fierro district, Grant County, New Mexico [abs.]: New Mexico Geology, v. 5, no. 4, p. 84.
Graeme, R.W., IV,, and Graeme, D.L., 1983, Azurites from the Hanover #2 Mine, Grant County, New Mexico [abs.]: 4th Annual New Mexico Mineral Symposium proceedings, p. 5 (unpaginated).
Graeme, R.W., IV, and Graeme, D.L., 1985, Zinc mineralogy of the Hanover area, Grant County, New Mexico [abs.]: New Mexico Geology, v. 7, no. 2, p. 41.
Graf, D.L., 1949, Trace-element studies, Santa Rita, New Mexico: New York, Columbia University, unpublished Ph. D. dissertation, unknown p.
Gramont, Bertrand, 1987, Carbonate sedimentology of the Virgilian part of the Horquilla Formation, Big Hatchet Peak area, Hidalgo County, New Mexico: Socorro, New Mexico Institute of Mining and Technology, unpublished Master's thesis, 222 p.
Gramont, B.P., and Johnson, D.B., 1986, Depositional environment of the upper Horquilla Formation (Permian not included) exposed in the west face of Big Hatchet Peak, Hidalgo County, New Mexico [abs.]: New Mexico Geology, v. 8, no. 3, p. 69.
Granger, H.C., 1952, Uranium occurrences on the Merry Widow claim, White Signal District, Grant County, New Mexico: U.S. Geological Survey Circular 189, 16 p. 4 maps.
Grauch, V.J.S., 1987, Interpretive aeromagnetic map using the horizontal gradient, Lake City area, San Juan Mountains, Colorado: U.S. Geological Survey Geophysical Investigations Map GP-974, scale 1:48,000.
Grauch, V.J.S., and Hudson Mark, R., 1987, Summary of natural remanent magnetization, magnetic susceptibility, and density measurements from Lake City caldera area, San Juan mountain, Colorado: U.S. Geological Survey Open-File 87-182, 60 p.
Gray, Floyd, Tosdal, R.M., Peterson, J.A., Cox, D.P., Miller, R.J., Kelin, D.P., Theobald, P.K., Haxel, G.P., Grubensky, Michael, Raines, Gary, Barton, H.N., Singer, D.A., and Eppinger, Robert, 1992, The Conterminous United States Mineral Assessment Program --Background information to accompany folio of geologic, geochemical, geophysical, and mineral resources maps of the Ajo and Lukeville 1° x 2° quadrangles, Arizona: U.S. Geological Survey Circular 1082, 27 p.
Greenwood, E., and Kottlowski, F.E., 1975 Geology of the Pedrogosa Basin in southwesternmost New Mexico and adjoining areas, *in* Exploration from the Mountains to the Basin: El Paso Geological Society, p. 29-36.
Greenwood, E., Kottlowski, F.E., and Armstrong, A.K., 1970, Upper Paleozoic and Cretaceous stratigraphy of the Hidalgo County area, New Mexico, *in* Woodward, L.A., ed., Guidebook of the Tyrone-Big Hatchet Mountains-Florida Mountains Region: New Mexico Geological Society, 21st Annual Field Conference, p. 33-43.

Greenwood, E., Kottlowski, F.E., and Thompson, S., III, 1977, Petroleum potential and stratigraphy of Pedregosa Basin; comparison with Permian and Orogrande basins: American Association of Petroleum Geologists Bulletin, v. 61, no. 9, p. 1448-1469.

Greet, C.B., 1987, A stratigraphic and petrographic analysis of the "Abo" Formation in the Santa Rita, New Mexico, area: Austin, Texas, Stephen F. Austin State University, unpublished Master's thesis, 95 p.

Grew, E.S., 1979, Al-Si disorder of K-feldspar in crustal xenoliths at Kilbourne Hole, New Mexico: American Mineralogist, v. 64, no. 7-8, p. 912-916.

Griffitts, W.R., 1965, Beryllium, *in* Mineral and water resources of New Mexico: U.S. Congress, 89th, 1st session, Senate Committee on Interior and Insular Affairs: New Mexico Bureau of Mines and Mineral Resources Bulletin 87, p. 196-200.

Griggs, R.L., and Wagner, H.C., 1966, Geology and ore deposits of the Steeple Rock mining district, Grant County, New Mexico, *in* Contributions to Economic Geology: U.S. Geological Survey Bulletin 1222E, p. 29.

Griswold, G.B., 1961, Mineral deposits of Luna County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 72, 157 p.

Griswold, G.B., 1974, Mineral deposits, Florida Mountains, *in* Corbitt, L.L., ed., Geology of the Florida Mountains, Luna County New Mexico: El Paso Geological Society, Guidebook 8, p. 30-35.

Griswold, G.B., Boy, R., Olson, R.R., and Zrinscak, P., 1989, Reconnaissance gold geochemical survey of five selected areas in southwestern New Mexico: New Mexico Bureau of Mines and Mineral Resources Open File Report OF-357, 19 p.

Gross, G.A., 1984, Skarn iron, *in* Eckstrand, O.R., ed., Canadian mineral deposit types--a geological synopsis: Geological Survey of Canada Economic Geology Report 36, p. 57.

Gross, G.A., and Rose, E.R., 1984, Mafic intrusion-hosted titanium-iron, *in* Eckstrand, O.R., ed., Canadian mineral deposit types--a geological synopsis: Geological Survey of Canada Economic Geology Report 36, p. 47.

Gross, J.T., and Giordano, T.H., 1985, The Las Cruces geothermal field--A flow model [abs.]: New Mexico Geology, v. 7, no. 3, p. 64.

Gross, J.T., and Icerman, L., 1983, Subsurface investigations for the area surrounding Tortugas Mountain, Doña Ana County, New Mexico: New Mexico Research and Development Institute, Report 2-67-2238(2), 70 p.

Gude, A.J., and Sheppard, R.A., 1988, A zeolithic tuff in a lacustrine facies of the Gila Conglomerate near Buckhorn, Grant County, New Mexico: U.S. Geological Survey Bulletin 1763, 22 p.

Guilbert, J.M., 1989, The geology of southwestern North American porphyry base metal deposits, *in* Drewes, Harald, and Dyer, Russ, 1989, Tectonics of the eastern part of the Cordilleran Orogenic Belt, Chihuahua, New Mexico, and Arizona, Field Trip Guidebook T121, 28th International Geological Congress: American Geophysical Union, Washington, D.C., p. 75-82.

Gunaji, N.N., Chaturvedi, L., Thode, E., LaFrance, L., Swanberg, C.A., and Walvekar, A., 1978, A geothermal field near New Mexico State University and its potential as campus energy supplier, *in* Combs, J., ed., Geothermal energy--A novelty becomes a resource: Transactions, Geothermal Resources Council, v. 2, sec. 2 (Hilo, Hawaii), p. 241-244.

Hair, G.L., 1976a, The Upper Pennsylvania Panther Seep Formation (Virgilian) of the Franklin Mountains, Doña Ana County, New Mexico, and El Paso County, Texas, *in* LeMone, D.V., and Lovejoy, E.M.P., eds., El Paso Geological Society symposium on the Franklin Mountains, p. 61-66.b

Hair, G.L., 1976b, Stratigraphy and microfacies analysis of Panther Seep Formation (Virgilian), Franklin Mountains, Texas, New Mexico: El Paso, University of Texas, unpublished Master's thesis, 70 p.

Hall, R.B., 1978, World nonbauxite aluminum resources; alunite: U.S. Geological Survey Professional Paper 1076-A, 35 p.
Hall, R.B. and Bauer, C.W., 1983, Alunite, *in* Lefond, S.J., ed., Industrial Minerals and Rocks (5th ed.): New York, Society of Mining Engineers, p. 417-434.
Hamilton, Warren, 1978, Mesozoic tectonics of the western United States, *in* Howell, D.G., and McDougall, K.A., eds., Mesozoic paleogeography of the western United States, Pacific Coast Paleogeography Symposium 2, Society of Economic Paleontologists and Mineralogists, Pacific Section, p. 33-70.
Hammarstrom, J.M., Drewes, Harald, Friedman, J.D., Klein, D.P., Kulik, D.M., Watts, K.C., Jr., Pitkin, J.A., Simpson, S.L., and Theodore, T.G., 1988, Preliminary mineral resource assessment of the Douglas 1°x2° quadrangle, Arizona-New Mexico: U.S. Geological Survey Administrative Report, 228 p., including indices.
Hammond, J., 1973, The Stephenson-Bennett Mine: The Mineralogical Record, v. 4, no. 1, p. 31-35.
Hammond, J., 1989, The Stephenson-Bennett Mine: The Mineralogical Record, v. 20, no. 1, p. 25-30.
Harben, P.W., and Bates, R.L., 1984, Geology of the nonmetallics: Metal Bulletin, New York.
Harbour, R.L., 1960, Road log from las Cruces to Vinton Canyon and Anthony Gap--Pennsylvanian localities in the northern Franklin Mountains: Roswell Geological Society Guidebook, Northern Franklin Mountains and southern San Andres Mountains, p. 11-33.
Harbour, R.L., 1972, Geology of the northern Franklin Mountains: U.S. Geological Survey Bulletin 1298, 129 p.
Harder, V.M., 1986, Fluorite; a new fission track age dating mineral [abs.]: Geological Society of America Abstracts with Programs, v. 18, no. 6, p. 628.
Hardwick, W.R., 1958, Open-pit mining methods and practices at the Chino Mines Division, Kennecott Copper Corp., Grant County, New Mexico: U.S. Bureau of Mines, Information Circular 7837, 64 p.
Harley, G.T., 1934, The geology and ore deposits of Sierra County, New Mexico: New Mexico Bureau of Mines and Mineral Resource, Bulletin 10, 220 p.
Harrer, C.M., 1965, Iron, *in* Mineral and water resources of New Mexico: U.S. Congress, 89th, 1st session, Senate Committee on Interior and Insular Affairs: New Mexico Bureau of Mines and Mineral Resources Bulletin 87, p. 176-183.
Harrer, C.M., and Kelly, F.J., 1963, Reconnaissance of iron resources in New Mexico: U.S. Bureau of Mines, Information Circular 8190, 112 p.
Harris, A.H., 1987, Reconstruction of mid-Wisconsin environments in southern New Mexico: National Geographic Research, v. 3, no. 2, p. 142-151.
Harris, A.H., Smartt, R.A., and Smartt, W.R., 1973, *Cryptotis parva* from the Pleistocene of New Mexico: Journal of Mammalia, v. 54, no. 2, p. 512-513.
Harrison, R.W., 1990, Cenozoic stratigraphy, structure, and epithermal mineralization of the north-central Black Range, New Mexico, in the regional geologic framework of south-central New Mexico: Socorro, New Mexico Institute of Mining and Technology, Ph.D. Dissertation, 525 p.
Harrison, R.W., Dymek, R.F., and Shelton, K.L., 1989, Early Tertiary wrench-fault tectonics along the eastern flank of the Black Range, southwestern New Mexico [abs.]: Geological Society of America Annual Meeting, Abstracts with Programs, v. 21, no. 6, p. 203.
Harrison, R.W., Geissman, J.W., Elston, W.E., and Keller, G.R., 1991, Multiple periods of Laramide tectonism in southwestern New Mexico [abs.]: Geological Society of America, Rocky Mountain Section, Abstracts with Programs, v. 23, no. 4, p. 31.
Hart, S.R., Padovani, E., and Richardson, S., 1980, Geochemistry of lower crustal granulite xenoliths, Kilbourne Hole, New Mexico [abs.]: International Geological Congress Abstracts, no. 26, v. 2, p. 775.

Hart, S.R., Padovani, E.R., and Roden, M.K., 1979, Sr-isotopic relationships in lower crustal nodules from Kilbourne Hole, New Mexico [abs.]: Geological Society of America Abstracts with Programs, v. 11, no. 7, p. 439.

Hassemer, J.R., Ficklin, W.H., Motooka, J.M., and Watts, K.C., 1983, Analytical results for 328 water samples from the Silver City 1°x2° quadrangle, Arizona and New Mexico: U.S. Geological Survey Open-File Report 83-0084, 42 p.

Hathaway, D.L., 1988, Hydrogeologic effects of dewatering an open-pit copper mine near Tyrone, New Mexico [abs.]: New Mexico Geology, v. 10, no. 3, p. 66.

Hatton, K.S., 1981, Geothermal energy, *in* New Mexico's energy resources '80: New Mexico Bureau of Mines and Mineral Resources Circular 181, p. 50-59.

Hatton, K.S., Barker, J.M., Glomer, N.A., Campbell, K., Hemenway, L., and Mansell, M., compilers, 1994, Mines, mills, and quarries in New Mexico: New Mexico Bureau of Mines and Mineral Resources, 66 p.

Hatton, K.S., Barker, J.M., Hallett, R.B., Hemenway, Lynne, Campbell, Kathryn, and King, R.S., compilers, 1992, Mines, mills and quarries in New Mexico: New Mexico Bureau of Mines and Mineral Resources, 66 p.

Hawkins, D.B., and Stephens, D.B., 1983, Ground-water modeling in a southwestern alluvial basin: Ground Water, v. 21, no. 6, p. 733-739.

Hawley, J.W., 1965, Geomorphic surfaces along the Rio Grande valley from El Paso, Texas, to Caballo Reservoir, New Mexico, *in* Fitzsimmons, J.P., and Lochman-Balk, Christina, eds., Guidebook of southwestern New Mexico II: New Mexico Geological Society, 16th Field Conference, p. 188-198.

Hawley, J.W., 1975a, The Desert Soil-Geomorphology Project, *in* Seager, W.R., Clemons, R.E., and Callender, J.F., eds., Guidebook of the Las Cruces Country: New Mexico Geological Society, 26th Annual Field Conference, p. 183-185.

Hawley, J.W., 1975b, Quaternary history of Doña Ana County region, south-central New Mexico, *in* Seager, W.R., Clemons, R.E., and Callender, J.F., eds., Guidebook of the Las Cruces Country: New Mexico Geological Society, 26th Annual Field Conference, p. 191-201.

Hawley, J.W., 1978, Guidebook to the Rio Grande rift in New Mexico and Colorado: New Mexico Bureau of Mines and Mineral Resources Circular 163, 241 p.

Hawley, J.W., 1981, Pleistocene and Pliocene history of the international boundary area, southern New Mexico, *in* Hoffer, J.M., and Hoffer, R.L., eds., Geology of the border--Southern New Mexico-northern Chihuahua: El Paso Geological Society Guidebook, p. 26-32.

Hawley, J.W., 1983, Quaternary geology of the Rhodes Canyon site, *in* The prehistory of Rhodes Canyon, New Mexico: Tularosa, New Mexico, Human Systems Research, Inc., p. 17-32.

Hawley, J.W., and Kottlowski, F.E., 1965a, Road log from Las Cruces to Nutt, New Mexico; *in* Fitzsimmons, J.P., and Lochman-Balk, Christina, eds., Guidebook of southwestern New Mexico II: New Mexico Geological Society, 16th Field Conference, p. 15-27 .

Hawley, J.W., and Kottlowski, F.E., 1965b, Road log from Lordsburg to San Simon Valley; *in* Fitzsimmons, J.P., and Lochman-Balk, Christina, eds., Guidebook of southwestern New Mexico II: New Mexico Geological Society, 16th Field Conference, p. 76-81.

Hawley, J.W., and Kottlowski, F.E., 1969, Quaternary geology of the south-central New Mexico border region, *in* Kottlowski, F.E., and LeMone, D.V., eds., Border Stratigraphy Symposium: New Mexico Bureau of Mines and Mineral Resources Circular 104, p. 89-104.

Hawley, J.W., Kottlowski, F.E., Strain, W.S., Seager, W.R., King, W.E., and LeMone, D.V., 1969, The Santa Fe Group in south-central New Mexico border region, *in* Kottlowski, F.E., and LeMone, D.V., eds., Border Stratigraphy Symposium: New Mexico Bureau of Mines and Mineral Resources Circular 104, p. 52-67.

Hawley, J.W., and Seager, W.R., 1978, New Mexico-Texas State line to Elephant Butte Reservoir, *in* Hawley, J.W., compiler, Guidebook to Rio Grande rift in New Mexico and Colorado: New Mexico Bureau of Mines and Mineral Resources Circular 163, p. 71-89.

Hawley, J.W., Seager, W.R., and Clemons, R.E., 1975, Third Day road log from Las Cruces to north Mesilla Valley, Cedar Hills, San Diego Mountain, and Rincon area, *in* Seager, W.R., Clemons, R.E., and Callender, J.F., eds., Las Cruces Country: New Mexico Geological Society 26th field conference guidebook, p. 35-53.

Hay, R.L., 1966, Zeolites and zeolitic reactions in sedimentary rocks: Geological Society of America Special Paper 85, 130 p.

Hay, R.L., and Sheppard, R.A., 1993, Zeolites in open hydrologic systems, *in* Mumpton, F.A., ed., Mineralogy and geology of natural zeolites: Brockport, N.Y., International Committee on Natural Zeolites, p. 77-84.

Hayba, D.O., Bethke, P.M., Heald, Pamela, and Foley, N.K., 1985, Geologic, mineralogic, and geochemical characteristics of volcanic-hosted epithermal precious-metal deposits, *in* Berger, B.R., and Bethke, P.M., eds., Geology and geochemistry of epithermal systems: Reviews in Economic Geology, v. 2, p. 129-167.

Hayden, F.V., 1869, Geological report of the exploration of the Yellowstone and Missouri rivers, under the direction of W.F. Raynolds, 1859–60: Washington, D.C., U.S. 40th Congress, 2d session, Senate Executive Document 77, 174 p.

Hayes, C.W., 1907, The Gila River alum deposits: U.S. Geological Survey Bulletin 315, p. 215-223.

Hayes, P.T., 1970, Cretaceous paleogeography of southeastern Arizona and adjacent areas: U.S. Geological Survey Professional Paper 658-B, 42 p.

Hayes, P.T., 1972, Stratigraphic nomenclature of Cambrian and Lower Ordovician rocks of easternmost southern Arizona and adjacent westernmost New Mexico: U.S. Geological Survey Bulletin 1372-B, p. B1-B21.

Hayes, P.T., 1975, Cambrian and Ordovician rocks of southern Arizona and New Mexico and westernmost Texas: U.S. Geological Survey Professional Paper 873, 98 p.

Hayes, P.T., 1978, Cambrian and Ordovician rocks of southeastern Arizona and southwestern New Mexico, *in* Callender, J.F., Wilt, J.C., Clemons, R.E., and James, H.L., eds., Land of Cochise, southeastern Arizona: New Mexico Geological Society, 29th Annual Field Conference, Guidebook, p. 165-173.

Hayes, P.T., 1982, Geologic map of Bunk Robinson Peak and Whitmire Canyon Roadless Areas, Coronado National Forest, New Mexico, and Cochise County, Arizona: U.S. Geological Survey Miscellaneous Field Studies Map MF-1425-A, 5 p.

Hayes, P.T., and Brown, S.D., 1984, Bunk Robinson Peak and Whitmire Canyon Roadless Areas, New Mexico and Arizona, *in* Marsh, S.P., Kropschot, S.J., and Dickinson, R.G., ed., Wilderness mineral potential; assessment of mineral-resource potential in U.S. Forest Service lands studied 1964-1984: U.S. Geological Survey Professional Paper 1300, p. 799-800.

Hayes, P.T., and Landis, E.R., 1965, Paleozoic stratigraphy of the southern part of the Mule Mountains, Arizona: U.S. Geological Survey Bulletin 1201–F, p. F1–F43.

Hayes, P.T., and Raup, R.B., 1968, Geologic map of the Huachuca and Mustang Mountains, southeastern Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map I–0509, scale 1:48,000.

Hayes, P.T., Simons, F.S., and Raup, R.B., 1965, Lower Mesozoic extrusive rocks in southeastern Arizona—The Canelo Hills Volcanics: U.S. Geological Survey Bulletin 1194–M, p. M1–M9.

Hayes, P.T., Watts, K.C., Hassemer, J.R., and Brown, S.D., 1983, Mineral resource potential of Bunk Robinson Peak and Whitmire Canyon Roadless Areas, Hidalgo County, New Mexico, and Cochise County, Arizona: U.S. Geological Survey Miscellaneous Field Studies Map MF-1425-B, scale 1:62,500.

Haynes, P.E., 1982, Zeolite minerals found near the Gila Cliff Dwelling National Monument [abs.]: Socorro, 3rd Biennial New Mexico Mineral Symposium, Proceedings, unpaginated.

Haynes, P.E., 1983, Zeolite minerals found near the Gila Cliff Dwellings National Monument [abs.]: New Mexico Geology, Abstracts of the New Mexico Minerals Symposium, Nov. 13-14, 1982, v. 5, no. 4, p. 84–85.

Hazen Research, Inc., 1979, Consulting service at Mining and Milling Corporation of America, core-drilling program on the Winkler Anticline, Hachita, Hidalgo County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Open File Report 108, 32 p.

Hedlund, D. C., 1974, Age and structural setting of base-metal mineralization in the Hillsboro-San Lorenzo area, southwestern New Mexico (abst.); in Siemers, C. T., Woodward, L. A., and Callender, J. F., eds., Ghost Ranch: New Mexico Geological Society, Guidebook 25, pp. 378-379.

Hedlund, D. C., 1977a, Mineral resources of the Hillsboro and San Lorenzo quadrangles, New Mexico: U. S. Geological Survey, Miscellaneous Field Studies Map MF-900B, scale 1:48,000.

Hedlund, D.C., 1977b, Geologic map of the Hillsboro and San Lorenzo quadrangles, Sierra and Grant Counties, New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map 900-A, scale 1:48,000

Hedlund, D.C., investigator, 1978a, Tertiary volcanic rocks in southwestern New Mexico: U.S. Geological Survey Professional Paper 1100, p. 74.

Hedlund, D.C., 1978b, Geologic map of the C-Bar Ranch quadrangle, Grant County, New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map MF-1039; scale 1:24,000.

Hedlund, D.C., 1978c, Geologic map of the Burro Peak quadrangle, Grant County, New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map MF-1040; scale 1:24,000.

Hedlund, D.C., 1978d, Geologic map of the Soldiers Farewell Hill quadrangle, New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map MF-1033; scale 1:24,000.

Hedlund, D.C., 1978e, Geologic map of the Ninety-six Ranch quadrangle, New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map MF-1034; scale 1:24,000.

Hedlund, D.C., 1978f, Geologic map of the Gold Hill quadrangle, New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map MF-1035; scale 1:24,000.

Hedlund, D. C., 1978g, Geologic map of the Tyrone quadrangle, Grant County, New Mexico: U. S. Geological Survey, Miscellaneous Field Studies Map MF-1037, scale 1:24,000.

Hedlund, D.C., 1978h, Geologic map of the Werney Hill quadrangle, Grant County, New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map MF-1038; scale 1:24,000.

Hedlund, D.C., 1978j, Geologic map of the White Signal quadrangle, Grant County, New Mexico: U. S. Geological Survey, Miscellaneous Field Studies Map MF-1041, scale 1:24,000.

Hedlund, D. C., 1978k, Geologic map of the Wind Mountain quadrangle, Grant County, New Mexico: U. S. Geological Survey, Miscellaneous Field Studies Map MF-1031, scale 1:24,000.

Hedlund, D.C., 1980, Geologic map of the Redrock NE quadrangle, Grant County, New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map MF-1264, scale 1:24,000.

Hedlund, D.C., 1985a, Geology, mines, and prospects of the Tyrone stock and vicinity, Grant County, New Mexico: U.S. Geological Survey Open-File Report OF 85-232, 31 p.

Hedlund, D.C., 1985b, Economic geology of some selected mines in the Hillsboro and San Lorenzo quadrangles, Grant and Sierra Counties, New Mexico: U.S. Geological Survey Open-File Report 85-456, 76 p.

Hedlund, D.C., 1990a, Geology and mineral deposits of the Steeple Rock and Duncan mining districts, Grant and Hidalgo Counties, New Mexico, and Greenlee County, Arizona: U.S. Geological Survey Open-File Report 90-239, 27 p.

Hedlund, D.C., 1990b, Geologic map and sections of the Steeple Rock quadrangle, Grant and Hidalgo Counties, New Mexico, and Greenlee County, Arizona: U.S. Geological Survey Open-File Report 90-240, scale 1:24,000, 14 p.

Hedlund, D.C., 1990c, Preliminary geologic map and sections of the Walker Canyon quadrangle, Grant and Hidalgo Counties, New Mexico: U.S. Geological Survey Open-File Report 92-531-M.

Hedlund, D.C., 1990d, Preliminary geologic map of the Goat Camp Spring quadrangle, Grant and Hidalgo counties, New Mexico and Greenlee County, Arizona: U.S. Geological Survey Open-File Report 92-490, scale 1:24,000.

Hedlund, D.C., 1990e, Preliminary geologic map of the Applegate Mountain quadrangle, Grant County, New Mexico: U.S. Geological Survey Open-File Report 90-0425 (also Master's thesis, New Mexico Institute of Mining and Technology, 1993), 71 p., scale 1:24,000.

Hedlund, D.C., 1991, Preliminary geologic map of the Crookson Peak quadrangle, Grant County, New Mexico: U.S. Geological Survey Open-File Report 90-0252, scale 1:24,000.

Hedlund, D.C., 1993, Geologic map of the Tillie Hall Peak quadrangle, Greenlee County, Arizona, and Grant County, New Mexico: U.S. Geological Survey Geologic Quadrangle Map GQ-1715, scale 1:24,000.

Hedlund, D.C., and Finnell, T.L., 1990, Preliminary geologic map and sections of part of the Canador Peak 15' quadrangle, Grant and Hidalgo Counties, New Mexico: U.S. Geological Survey Open-File Report 90-0505, scale 1:24,000.

Hedlund, D.C., Stacey, J.S., and Marvin, R.F., 1981, Precambrian dated sequence, Burro Mountains, New Mexico: U.S. Geological Survey Professional Paper 1275, p. 70-71.

Hennessy, J.T., Kies, B., Gibbens, R.P., and Tromble, J.M., 1986, Soil sorting by forty-five years of wind erosion on a southern New Mexico range: Soil Science Society of America Journal, v. 50, no. 2, p. 391-394.

Hernandez, J.W., 1973, An environmental study of a proposed Southwest copper refinery: American Smelting and Refining Company: New Mexico Environmental Institute.

Hernon, R.M., 1935, The Paradise Formation and its fauna: Journal of Paleontology, v. 9, p. 653-696.

Hernon, R.M., compiler, 1949, Geology and ore deposits of Silver City region, New Mexico: West Texas Geological Society and Southwestern New Mexico Section, American Institute of Mining and Metallurgical Engineers, Guidebook, Field Trip no. 3, 45 p.

Hernon, R.M., and Jones, W.R., 1968, Ore deposits of the Central mining district, Grant County, New Mexico; in Ore deposits of the United States, 1933-1967: AIME Graton-Sales volume, p. 1211-1233.

Hernon, R.M., Jones, W.R., and Moore, S.L., 1953, Some geological features of the Santa Rita quadrangle, New Mexico, *in* Kottlowski, F.E., ed., Southwestern New Mexico: New Mexico Geological Society, 4th Annual Field Conference, Guidebook, p. 117-130.

Hernon, R.M., Jones, W.R., and Moore, S.L., 1964, Geology of the Santa Rita quadrangle, New Mexico: U.S. Geological Survey Geologic Quadrangle Map GQ–306, scale 1:24,000.

Herrick, C.L., 1900, The geology of the White Sands of New Mexico: Journal of Geology, v. 8, p. 112-128.

Hess, F.L., 1922, Radium, uranium and vanadium, *in* Mineral resources of the United States, 1920, Pt. 1, metals: U.S. Geological Survey, p. 415-417.
Hess, F.L., 1924, Radium, uranium, and vanadium, *in* Mineral resources of the United States, 1921, part 1, metals: U.S. Geological Survey, p. 225-233.
Hewitt, C.H., 1957, Geology of the Burro Mountains-Redrock area, New Mexico: Ann Arbor, University of Michigan, unpublished Ph. D. dissertation, unknown p.
Hewitt, C.H., 1959, Geology and mineral deposits of the northern Big Burro Mountains-Redrock area, Grant County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 60, 151 p.
Heyl, A.V., 1983a, Some major lineaments reflecting deep-seated fracture zones in the central United States, and mineral districts related to the zones: Global Tectonics and Metallogeny, v. 2, p. 75-77.
Heyl, A.V., 1983b, Some mineral localities in the Black Range and vicinity, south-central New Mexico [abs.]: Abstracts; New Mexico mineral symposium, unpaginated.
Heyl, A.V., 1990, Minerals of the Black Range and vicinity, southwest New Mexico [abs.]: New Mexico mineral symposium, p. 31. [Also New Mexico Geology, v. 12, no. 2, p. 31.]
Heyl, A.V., and Bozion, C.N., 1962, Oxidized zinc deposits of the United States: U.S. Geological Survey Bulletin 1135-A, 49 p.
Heylman, E.B., 1986, East Potrillo Mountains, New Mexico: California Mining Journal, v. 55, no. 5, p. 10-12.
Hildenbrand, T.G., 1983, FFTFIL-A filtering program based on two-dimensional Fourier analysis of geophysical data: U.S. Geological Survey Open-File Report 83-237, 60 p.
Hill, R.T., 1901, Geographic and geologic features of Mexico: Engineering and Mining Journal, v. 72, p. 561-564.
Hill, G.T., 1994, Geochemistry of southwestern New Mexico fluorite deposits with possible base and precious metals exploration significance: Socorro, New Mexico Institute of Mining and Technology, M.S. thesis, 44 p.
Hill, J.D., 1924, The mining districts of southwestern New Mexico: Boulder, University of Colorado, unpublished Master's thesis, 134 p.
Hill, R. S., 1946, Exploration of Grey Eagle, Grandview, and Royal John claims Grant and Sierra Counties, New Mexico: U. S. Bureau of Mines, Report of Investigations 3904, 31 p.
Hillesland, L.L., Hawkins, R.B., and Worthington, W.T., 1995, The geology and mineralization of the Continental mine area, Grant County, New Mexico; *in* Pierce, F.W., and Bolm J.G., eds., Porphyry copper deposits of the American Cordillera: Arizona Geological Society Digest 20, p. 473-483.
Hillesland, L.L., Worthington, W.T., and Hawkins, R.B., 1994, General geology of the Continental mine, Grant County, New Mexico; in Trip 10 and 13; Tyrone, Piños Altos, Chino, Continental, Central district, New Mexico: Bootprints along the Cordillera, Field Guide, 22 p.
Hilpert, L.S., 1965, Uranium, *in* Mineral and water resources of New Mexico: U.S. Congress, 89th, 1st session, Senate Committee on Interior and Insular Affairs: New Mexico Bureau of Mines and Mineral Resources Bulletin 87, p. 209-226.
Hiss, W.L., 1975, Scenes from the past; II, *in* Seager, W.R., Clemons, R.E., and Callender, J.F., eds., Guidebook of the Las Cruces Country: New Mexico Geological Society, 26th Annual Field Conference, p. 75-80.
Hlava, P.F., Modreski, P.J., and DeMark, R.S., 1983, A New Mexico occurrence of a new molybdate-arsenate member of the fornacite group of minerals, *in* Anthony, J.W., ed., Oxidation mineralogy of base metal deposits: Proceedings of the 5th joint Mineralogical Society of America/Friends of Mineralogy Symposium.

Hobblitt, R.P., Larson, E.E., and Walker, T.R., 1974, Chemical remagnetization of Miocene red beds in southern New Mexico: EOS, American Geophysical Union Transactions, v. 56, no. 12, p. 1110.

Hobbs, S.W, 1965, Tungsten, *in* Mineral and water resources of New Mexico: U.S. Congress, 89th, 1st session, Senate Committee on Interior and Insular Affairs: New Mexico Bureau of Mines and Mineral Resources Bulletin 87, p. 241-255.

Hodges, F., 1931, Milling methods at the Hurley plant of the Nevada Consolidated Copper Co., Hurley, New Mexico: U.S. Bureau of Mines, Information Circular 6394, 17 p.

Hoffer, J.M., 1969a, Geology and petrography of the Campus Andesite pluton, El Paso County, Texas, *in* Cordoba, D.A., Wengerd, S.A., and Shomaker, J., eds., Guidebook of the Border Region; Chihuahua and the United States: New Mexico Geological Society, 20th Annual Field Conference, p. 102-107.

Hoffer, J.M., 1969b, Volcanic history of the Black Mountain-Santo Tomas basalts, Potrillo volcanics, Doña Ana County, New Mexico, *in* Cordoba, D.A., Wengerd, S.A., and Shomaker, J., eds., Guidebook of the Border Region; Chihuahua and the United States: New Mexico Geological Society, 20th Annual Field Conference, p. 108-114.

Hoffer, J.M., 1970, Petrology and mineralogy of the Campus Andesite pluton, El Paso, Texas: Geological Society of America Bulletin, v. 81, p. 2129-2136.

Hoffer, J.M., 1971a, Herradura: A new lava flow feature: Geological Society of America Bulletin, v. 82, p. 2949-2954.

Hoffer, J.M., 1971b, Mineralogy and petrology of the Santo Tomas-Black Mountain basalt field, Potrillo volcanics, south-central New Mexico: Geological Society of America Bulletin, v. 82, p. 603-612.

Hoffer, J.M., 1973b, Quaternary basalts of the West Potrillo Mountains, southcentral New Mexico, *in* Hoffer, J.M., ed., The geology of southcentral Dona Ana County, New Mexico: El Paso Geological Society, 7th Annual Fieldguide, p. 26-32.

Hoffer, J.M., 1975a, A note on the volcanic features of the Aden Crater area, southcentral New Mexico, *in* Seager, W.R., Clemons, R.E., and Callender, J.F., eds., Guidebook of the Las Cruces Country: New Mexico Geological Society, 26th Annual Field Conference, p. 131-134.

Hoffer, J.M., 1975b, Basalt volcanism in the southern Rio Grande trench, *in* Exploration from the mountains to the basin: Transactions, Joint meeting, Southwest Section, American Association of Petroleum Geologists and Permian Basin Section, Society of Economic Paleontologists and Mineralogists, El Paso, Texas, p. 101-114.

Hoffer, J.M., 1976a, Geology of Potrillo Basalt Field, south-central New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 149, 30 p.

Hoffer, J.M., 1976b, The Potrillo Basalt Field, south-central New Mexico: New Mexico Bureau of Mines and Mineral Resources Special Publication 5, p. 89-92.

Hoffer, J.M., 1981, Late Cenozoic basalts of the southern Rio grande rift, southern New Mexico, West Texas, and northern Chihuahua, Mexico; Papers presented to the Conference on the processes of planetary rifting: Lunar and Planetary Institute Contribution 457, p. 141-144.

Hoffer, J.M., 1986, Subsurface volcanic stratigraphy, southern New Mexico, *in* Hoffer, J.M., ed., Geology of southcentral New Mexico: El Paso Geological Society Field Trip Guidebook, April 11, 1986, p. 119-122.

Hoffer, J.M., 1990, Geologic tour of Aden Crater: El Paso Geological Society, Guidebook to the Fall 1990 Field Trip, 42 p.

Hoffer, J.M., 1994, Pumice and pumicite in New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 140, 23 p.

Hoffer, J.M., Chen, W., McLemore, V.T., and Anthony, E.Y., 1991, Day 2--The Potrillo volcanic field, *in* Julian, Betsy, and Zidek, Jiri, Field guide to geologic excursions in New Mexico and adjacent areas of Texas and Colorado: New Mexico Bureau of Mines and Mineral Resources Bulletin 137, p. 12-19.

Hoffer, J.M., and Hoffer, R.L., 1973, Composition and structural state of feldspar inclusions from alkali olivine basalt, Potrillo basalt, southern New Mexico: Geological Society of America Bulletin 84, p. 2139-2142.

Hoffer, J.M., and Hoffer, R.L., 1981a, A note on Lower Cretaceous outcrops, southeastern Luna County, New Mexico, *in* Hoffer, J.M., and Hoffer, R.L., eds., Geology of the border; southern New Mexico-northern Chihuahua: El Paso Geological Society Guidebook, p. 54-56.

Hoffer, J.M., and Hoffer, R.L., 1981b, Geology of the East Potrillo Mountains, southern Doña Ana County, New Mexico, *in* Hoffer, J.M., and Hoffer, R.L., eds., Geology of the border; southern New Mexico-northern Chihuahua: El Paso Geological Society Guidebook, p. 57-61.

Hoffer, J.M., and Ortiz, T.S., 1981, The composition of feldspar megacrysts, Potrillo basalt, West Potrillo Mountains, southern New Mexico, *in* Hoffer, J.M., and Hoffer, R.L., eds., Geology of the border--Southern New Mexico-Northern Chihuahua: El Paso Geological Society, p. 73-78.

Hoffer, J.M., and Sheffield, T.M., 1981, Geology of the West Potrillo Mountains, south-central New Mexico: El Paso Geological Society, Guidebook, p. 79-82.

Hofstra, A.H., Daly, W.E., Birak, D.J., and Doe, T.C., 1991, Geologic framework and genesis of Carlin-type gold deposits in the Jerritt Canyon district, Nevada, USA, *in* Ladeira, E.A., Brazil Gold '91--The economics, geology, geochemistry, and genesis of gold deposits: Belo Horizonte, Brazil, May 13-17, 1991, Proceedings, Federal University of Minas Gerais, p. 77-87.

Hoggatt, W.C., Silberman, M.L., and Todd, V.R., 1977, K-Ar ages of intrusive rocks of the central Peloncillo Mountains, Hidalgo County, New Mexico: Isochron West, no. 19, p. 3-6.

Hohmann, G.W., and Jiracek, F.R., 1979, Bipole-dipole interpretation with three-dimensional models (including a field study of Las Alturas, New Mexico): Department of Energy Report DOE/ET/28392-29, ESL-20, 20 p.

Holser, W.T., 1953, Beryllium minerals in the Victorio Mountains, Luna County, New Mexico: American Mineralogist, v. 38, p. 599-611.

Homme, F.C., 1958, Contact metamorphism in the Tres Hermanas Mountains, Luna County, New Mexico: Albuquerque, University of New Mexico, M.S. thesis, 88 p.

Homme, F.C., and Rosenzweig, A., 1970, Contact metamorphism in the Tres Hermanas Mountains, Luna County, New Mexico, *in* Woodward, L.A., ed., Guidebook of the Tyrone-Big Hatchet Mountains-Florida Mountains Region: New Mexico Geological Society, 21st Annual Field Conference, p. 141-145.

Hook, S.C., 1983, Stratigraphy, paleontology, depositional framework, and nomenclature of marine Upper Cretaceous rocks, Socorro County, New Mexico, *in* Chapin, C.E., Socorro region II: New Mexico Geological Society, 34th Annual Field Conference, p. 165–172.

Hook, S.C., and Cobban, W.A., 1981, Late Greenhorn (mid-Cretaceous) discontinuity surfaces, southwest New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 180, p. 5-21.

Hook, S.C., Molenaar, C.M., and Cobban, W.A., 1983, Stratigraphy and revision of nomenclature of upper Cenomanian to Turonian (Upper Cretaceous) rock of west-central New Mexico; *in* Hook, S.C., Contributions to Mid-Cretaceous paleontology and stratigraphy of New

Mexico--Part II, New Mexico Bureau of Mines and Mineral Resources Circular 185, p. 7-28.
Hoover, D.B., and Tippens, C.L., 1975, A reconnaissance audio-magnetogelluric survey at Kilbourne Hole, New Mexico, *in* Seager, W.R., Clemons, R.E., and Callender, J.F., eds., Guidebook of the Las Cruces Country: New Mexico Geological Society, 26th Annual Field Conference, p. 277-278.
Hoover, J.D., Ensenat, S.E., Barnes, C.G., and Dyer, R., 1988, Early Trans-Pecos magmatism; petrology and geochemistry of Eocene rocks in the El Paso area, *in* Mack, G.H., Lawton, T.F., and Lucas, S.G., eds., Cretaceous and Laramide tectonic evolution of southwestern New Mexico: New Mexico Geological Society, 39th annual field conference, p. 108-118.
Hopkins, R.T., Barton, H.N., Bradley, Leon, and Day, G.W., 1988, Analytical results and sample locality maps of heavy-mineral-concentrate and rock samples from the Big Hatchet Mountains Wilderness Study Area (NM-030-035), Hidalgo County, New Mexico: U.S. Geological Survey Open-File Report 88-0502, 17 p., scale 1:24,000 [Microform].
Howard, E.V., 1963, A socioeconomic study of copper leaching at Santa Rita: Socorro, New Mexico Institute of Mining and Technology, unpublished Master's thesis, unknown p.
Hudson, J.S., 1984, Geology and hydrothermal alteration of the San Simon mining district south of Steins Pass, Peloncillo Mountains, Hidalgo County, New Mexico: Albuquerque, University of New Mexico, unpublished Master's thesis, 125 p.
Hunt, C.B., 1975, Why all the fuss about our environment?, *in* Seager, W.R., Clemons, R.E., and Callender, J.F., eds., Guidebook of the Las Cruces Country: New Mexico Geological Society, 26th Annual Field Conference, p. 187-194.
Hunt, C.B., 1978, Surficial geology of southwest New Mexico: New Mexico Bureau of Mines and Mineral Resources Geologic Map 42, scale 1:500,000.
Huntington, M.G., 1947, Atwood copper group, Lordsburg district, Hidalgo County, New Mexico: U.S. Bureau of Mines Report of Investigations 4029, 9 p.
Huspeni, J.R., Kesler, S.E., Ruiz, Joaquin, Zane, Tuta, Sutter, J.F., and Jones, L.M., 1984, Petrology and geochemistry of rhyolites associated with tin mineralization in northern Mexico: Economic Geology, v. 79, no. 1, p. 87-105.
Hutchins, M.F., 1983, Mineral resource areas of the Basin and Range Province of New Mexico: U.S. Geological Survey Open-File Report 83-0665, 16 p.
Hyde, T.G., 1984, Depositional environments, stratigraphy, and petrography of the Sarten Sandstone and related Lower Cretaceous formations, southwestern New Mexico: Las Cruces, New Mexico State University, unpublished Master's thesis, 46 p.
Icerman, L., and Gross, J., 1983, Subsurface investigations for the area surrounding Tortugas Mountain, Dona Ana County, New Mexico: Las Cruces, New Mexico State University Energy Institute, 70 p.
Icerman, L., and Lohse, R.L., 1983, Geothermal low-temperature reservoir assessment in Doña Ana County, New Mexico; Final report: Santa Fe, New Mexico Energy Research and Development Institute, report no. 2-69-2202, 188 p.
Ingalls, N., 1986, Field trip; New Mexican candyrock: Rock and Gem, v, 16, no. 10, p. 32-35.
Inglis, M., and Budge, T.K., 1984, Preliminary examination of TIMS data for geothermal resource exploration, *in* Morris-Jones, D.R., and Cook, J.J., eds., Remote sensing for exploration geology: Proceedings, International symposium on remote sensing of the environment, Third thematic conference, Apr. 16-19, 1984, v. 1, p. 315-320.
International Association of Geodesy and Geophysics, 1971, The Geodetic Reference System, 1967: International Association of Geodesy Special Publication No. 3, 116 p.
International Association of Geodesy, 1974, The International Association of Geodesy Special Publication No. 4, 194 p.

International Committee on Natural Zeolites, 1993, Program and abstracts: Zeolites '93, 4th International Conference on the occurrence, properties, and utilization of natural zeolites, Boise, Idaho, June 20-28, 1993, 225 p.
Irving, A.J., 1979, Kilbourne Hole spinel lherzolites--Samples of multiply depleted, enriched and deformed mantle: EOS, American Geophysical Union, Transactions, v. 60, no. 18, p. 418.
Izett, G.A., Wilcox, R.E., and Borchardt, G.A., 1972, Correlation of a volcanic ash bed in Pleistocene deposits near Mount Blanco, Texas with the Gua Pumice Bed of the Jemez Mountains, New Mexico: Quaternary Research, v. 2, p. 554-578.
Jackson, D.B., and Bisdorf, R.J., 1975, Direct-current soundings on the La Mesa surface near Kilbourne and Hunts holes, New Mexico, *in* Seager, W.R., Clemons, R.E., and Callender, J.F., eds., Guidebook of the Las Cruces Country: New Mexico Geological Society, 26th Annual Field Conference, p. 273-275.
Jagoutz, E., Carlson, R.W., and Lugmair, G.W., 1980, Equilibrated Nd-unequilibrated Sr isotopes in mantle xenoliths: Nature, v. 286, no. 5774, p. 708-710.
Jahns, R.H., 1944, Beryllium and tungsten deposits of the Iron Mountain district, Sierra and Socorro Counties, New Mexico: U.S. Geological Survey Bulletin 945-C, p. 45-79.
Jaksha, L.H., 1982, Reconnaissance seismic refraction-reflection surveys in southwest New Mexico: Bulletin Geological Society of America, v. 93, no. 10, p. 1030-1037.
Jaksha, L.H., and Locke, J., 1981, Seismicity near Albuquerque, New Mexico, 1976-1978: U.S. Geological Survey Open-File Report 81-0117, 18 p.
James, D.E., Padovani, E.R., and Hart, S.R., 1980, Preliminary results on the oxygen isotopic composition of the lower crust, Kilbourne Hole maar, New Mexico: Geophysical Research Letters, v. 7, no. 5, p. 321-324.
James, H.L., 1971, Southwestern New Mexico: Scenic Trips into the Geologic Past, no. 10, 80 p.
James, H.L., and McCall, W.B., 1965, Exit roadlog from Lordsburg to Las Cruces; *in* Fitzsimmons, J.P., and Lochman-Balk, Christina, eds., Guidebook of southwestern New Mexico II: New Mexico Geological Society, 16th Field Conference, p. 86-92.
James, W.C., and Mack, G.H., 1986, Abo-Hueco transition zone (Lower Permian) of the Robledo Mountains and adjacent areas of southwestern New Mexico, *in* Hoffer, J.M., ed., Geology of southcentral New Mexico: El Paso Geological Society Field Trip Guidebook, p. 67-72.
James, W.C., and Russo, J.F., 1988, Diagenesis of a mixed arenite petrofacies, Lobo Formation (Tertiary), southwestern New Mexico, *in* Mack, G.H., Lawton, T.F., and Lucas, S.G., eds., Cretaceous and Laramide tectonic evolution of southwestern New Mexico: New Mexico Geological Society, 39th Field Conference, Guidebook, p. 169-173.
Jaster, M.C., 1956, Perlite resources of the United States: U.S. Geological Survey Bulletin 1027-I, p. 375-404.
Jenkins, D.A., 1977, Geologic evaluation of the EPM mining claims, East Potrillo Mountains, Doña Ana County, New Mexico: Socorro, New Mexico Institute of Mining and Technology, unpublished Master's thesis, 109 p.
Jenness, J.E., Roggensack, K., and Lopez, D.A., 1984, Map showing outcrops of pre-Quaternary ash-flow tuff and laharic breccias, Basin and Range Province, New Mexico: U.S. Geological Survey Water Resources Investigations 83-4118-F, 21 p.
Jeske, R.E., 1987, Mineral resources of the Organ Mountains Wilderness Study Area (NM-030-074), Doña Ana County, New Mexico: U.S. Bureau of Mines, MLA 6-87, 81 p.
Jicha, H.L., Jr., 1954, Geology and mineral resources of Lake Valley quadrangle, Grant, Luna, and Sierra Counties, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 37, 93 p.

Jiracek, F.R., and Gerety, M.T., 1978, Comparison of surface and downhole resistivity mapping of geothermal reservoirs in New Mexico, *in* Combs, J., ed., Geothermal energy--A novelty becomes a resource: Transactions, Geothermal Resources Council, v. 2, sec. 2 (Hilo, Hawaii), p. 335-336.

Jiracek, G.R., and Smith, Christian, 1976, Deep resistivity investigations at two known geothermal resource areas (KGRAS) in New Mexico--Radium Springs and Lightning Dock; Tectonics and mineral resources of southwestern North America: New Mexico Geological Society Special Publication 6, p. 71-76.

Jiracek, G.R., Smith, C.S., Forsythe, G.T., and Dorn, G.A., 1975, Geothermal resistivity investigations in New Mexico: American Association of Petroleum Geologists Bulletin, v. 59, no. 5, p. 912-913.

John, D.A., Stewart, J.H., Kilburn, J.E., Silberling, N.J., and Rowan, L.C., 1993, Geology and mineral resources of the Reno 1°x2° quadrangle, Nevada and California: U.S. Geological Survey Bulletin 2019, 65 p.

Johnson, C.H., 1943, Steeple Rock district, Grant county, New Mexico: U.S. Bureau of Mines War Minerals Report 188, 11 p.

Johnson, C.M., 1991, Large-scale crust formation and lithosphere modification beneath middle to late Cenozoic calderas and volcanic fields, western North America: Journal Geophysical Research, v. 96, no. B8, p.13,485-13,507.

Johnson, K.E., 1983, Silver-nickel-cobalt-uranium mineralization and associated alteration in Black Hawk District, Grant County, New Mexico [abs.]: New Mexico Geology, v. 5, no. 3, p. 66.

Johnson, M.G., 1972, Placer gold deposits of New Mexico: U.S. Geological Survey Bulletin 1348, 46 p.

Johnson, W.D., Jr., Hawley, J.W., Stone, W.J., Kottlowski, F.E., Henry, C.D., and Price, J.G., 1989, Geology, *in* Bedinger, M.S., Sargent, K.A., and Langer, W.H., eds., Studies of geology and hydrology in the Basin and Range Province, southwestern United States, for isolation of high-level radioactive waste; characterization of the Rio Grande region, New Mexico and Texas: U.S. Geological Survey Professional Paper 1370-C, p. C7-C19.

Johnston, W.D., Jr., 1928, Fluorspar in New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 4, p. 61-88.

Jones, B.R., 1959, A sedimentary study of dune sands, Lamb and Bailey counties, Texas and White Sands National Monument: Lubbock, Texas Technical College, unpublished Master's thesis, unknown p.

Jones, E.L., Jr., 1920, Deposits of manganese ore in New Mexico: U.S. Geological Survey Bulletin 710, p. 37-60.

Jones, F.A., 1904, New Mexico mines and minerals: Santa Fe, The New Mexico Printing Company, p. 73-80.

Jones, F.A., 1905, Old mines and ghost camps of New Mexico: New Mexico Mines and Minerals, p. 213.

Jones, F.A., 1907, The Lordsburg mining region, New Mexico: Engineering and Mining Journal, v. 84, p. 444-445.

Jones, F.A., 1908a, Sylvanite, New Mexico--The new gold camp: Engineering and Mining Journal, v. 86, p. 1101-1103.

Jones, F.A., 1908b, The new camp of Sylvanite, New Mexico: Mining Science, v. 58, p. 489-490.

Jones, G.M., and Menzie, W.D., 1986a, Grade and tonnage model of W veins, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 65-66.

Jones, G.M., and Menzie, W.D., 1986b, Grade and tonnage model of Cu skarn deposits, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 86-89.

Jones, J.L., Kilburn, J.E., Zimbelman, D.R., and Siems, D.F., 1987, Analytical results and sample locality maps of heavy-mineral-concentrate and rock samples from the West Potrillo Mountains/Mt. Riley Wilderness Study Area (030-052), Luna and Doña Ana Counties, New Mexico: U.S. Geological Survey Open-File Report 87-265, 23 p.

Jones, T.S., 1992, "Manganese" *in* Mineral Commodity Summaries - 1991, US Bureau of Mines, pp 100 - 101.

Jones, W.R., 1965, Copper; *in* Mineral and water resources of New Mexico: U.S. Congress, 89th, 1st session, Senate Committee on Interior and Insular Affairs: New Mexico Bureau of Mines and Mineral Resources Bulletin 87, p. 160-176.

Jones, W.R., Case, J.E., and Pratt, W.P., 1964, Aeromagnetic and geologic map of part of the Silver City Mining Region, Grant County, New Mexico: U.S. Geological Survey Geophysical Investigations Map GP-424.

Jones, W. R., and Hernon, R. M., 1973, Ore deposits and rock alteration of the Santa Rita quadrangle, Grant County, New Mexico: U.S. Department of Commerce, National Technical Information Service PB 214, 371 102 p.

Jones, W.R., Hernon, R.M., and Moore, S.L., 1967, General geology of Santa Rita quadrangle, Grant County, New Mexico: U.S. Geological Survey Professional Paper 555, 144 p.

Jones, W.R., Hernon, R.M., and Pratt, W.P., 1961, Geologic events culminating in primary metallization in the Central mining district, Grant County, New Mexico, *in* Short papers in the geologic and hydrologic sciences: U.S. Geological Survey Professional Paper 424-C, p. C-11 to C-16.

Jones, W.R., Moore, S.L., and Pratt, W.P., 1970, Geologic map of the Fort Bayard quadrangle, Grant County, New Mexico: U.S. Geological Survey Geologic Quadrangle Map GQ-865, 4 p., scale 1:24,000.

Jordan, C.F., 1975, Lower Permian (Wolfcampian) sedimentation in the Orogrande Basin, New Mexico, *in* Seager, W.R., Clemons, R.E., and Callender, J.F., eds., Guidebook of the Las Cruces Country: New Mexico Geological Society, 26th Annual Field Conference, p. 109-117.

Julyan, B., 1986, Place names, *in* Williams, J.L., ed., New Mexico in Maps: Albuquerque, University of New Mexico Press, p. 308-310.

Kaczmarek, E.L., Jr., 1987, Depositional environments, sediment dispersal, and provenance of the Upper Cretaceous Colorado Formation, southwestern New Mexico: Las Cruces, New Mexico State University, unpublished Master's thesis, 107 p.

Kaczmarek, E.L., 1988, Depositional environments, sediment dispersal, and provenance of the Upper Cretaceous Colorado Formation, southwestern New Mexico [abs.]: Geological Society of America Abstracts with Programs, v. 20, no. 3, p. 172.

Kahn, P.A., 1987, Geology of Aden Crater, Doña Ana County, New Mexico: El Paso, University of Texas, unpublished Master's thesis, 90 p.

Kallo, Denes, and Sherry, H.S., eds., 1988, Occurrence, properties, and utilization of natural zeolites: Budapest, Akademiai Kiado, 857 p.

Keefer, K.D., and Brown, G.E., 1978, Crystal structures and compositions of sanidine and high albite in cryptoperthitic intergrowth: American Mineralogist, v. 63, nos. 11-12, p. 1264-1273.

Keith, S.B., 1986, Petrochemical variations in Laramide magmatism and their relationship to Laramide tectonic and metallogenic evolution in Arizona and adjacent regions, *in* Beatty,

B., and Wilkinson, P.A.K., eds., Frontiers in geology and ore deposits of Arizona and the southwest: Arizona Geological Society Digest, 16, p 89-101.
Keith, S.B., and Barrett, L.F., 1976, Tectonics of the central Dragoon Mountains—a new look, *in* Wilt, J.C., and Jenney, J.P., Tectonic digest: Arizona Geological Society Digest, v. 10, p. 169–204.
Keith, S.B., Gest, D.E., DeWitt, E.H., Tull, N.W., and Everson, B.A., 1983, Metallic mineral districts and production in Arizona: Arizona Bureau of Geology and Mineral Technology, Bulletin 194, 58 p.
Keller, G.R., Cordell, Lindrith, 1983, Bouguer gravity anomaly map of New Mexico, Geothermal resources of New Mexico scientific map series: Las Cruces, New Mexico, State University Energy Institute, 1:500,000.
Keller, G.R., Graham, R.G., and Roy, R.F., 1978, Regional geophysics of the southern Rio Grande rift, *in* Hawley, J.W., compiler, Guidebook to Rio Grande rift in New Mexico and Colorado: New Mexico Bureau of Mines and Mineral Resources Circular 163, p. 69-70.
Keller, G.R., Lidiak, E.G., Hinze, W.J., and Braile, L.W., 1983, The role of rifting in the tectonic development of the midcontinent, U.S.A.: Tectonophysics, v. 94, p. 391-412.
Keller, G.R., Morgan, P., and Seager, W.R., 1990, Crustal structure, gravity anomalies, and heat flow in the southern Rio Grande rift and their relationship to extensional tectonics: Tectonophysics, v. 174, p. 21-37.
Kelley, S., and Matheny, J.P., 1983, Geology of Anthony quadrangle, Doña Ana County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Geologic Map 54, scale 1:24,000.
Kelley, T.E., 1975, The Lost Padre Mine and the Organ mining district, *in* Seager, W.R., Clemons, R.E., and Callender, J.F., eds., Guidebook of the Las Cruces Country: New Mexico Geological Society, 26th Annual Field Conference, p. 163-165.
Kelley, V.C., 1949, Geology and economics of New Mexico iron-ore deposits: University of New Mexico Publications in Geology, no. 2, 246 p.
Kelley, 1951, Oolitic iron deposits of New Mexico: American Association of Petroleum Geologists Bulletin, v. 35, no. 10, p. 2199-2228.
Kelley, V.C., 1952, Tectonics of the Rio Grande depression of central New Mexico, *in* Johnson, R.B., and Read, C.B., Rio Grande Country: New Mexico Geological Society, 3rd Annual Field Conference, Guidebook, p. 93-105.
Kelley, V.C., 1955, Regional tectonics of south-central New Mexico, *in* Guidebook of south-central New Mexico: New Mexico Geological Society, 6th Field Conference, Guidebook, p. 96-104.
Kelley, V.C., 1979, Tectonics, middle Rio Grande rift, New Mexico, *in* Riecker, R.E., ed., Rio Grande rift--Tectonics and magmatism: Washington, D.C., American Geophysical Union, p. 57-70.
Kelley, V.C., and Bogart, L.E., 1952, Gym limestone, New Mexico: American Association of Petroleum Geologists Bulletin, v. 36, p. 1644-1648.
Kelley, V. C., and Branson, O. T., 1947, Shallow, high-temperature pegmatites, Grant County, New Mexico: Economic Geology, v. 42, no. 8, p. 699-712.
Kelley, V.C., and Furlow, J.W., 1965, Lower Paleozoic wedge edges in southcentral New Mexico--New control: Geological Society of America Bulletin, v. 76, p. 689-694.
Kelley, S.A., and Matheny, J.P., 1983, Geology of Anthony quadrangle, Dona Ana County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, scale 1:24,000.
Kelley, V.C., and Silver, C., 1952, Geology of the Caballo Mountains: New Mexico University Publications in Geology Series, no. 4, 286 p.

Kelley, V.C., Wood, G.H., Jr., and Kelly, V.C., 1946, Geology of the Lucero uplift, Valencia, Socorro, and Bernalillo Counties, New Mexico: U.S. Geological Survey Oil and Gas Investigations Map OM–0047.

Kennedy, W.J., Cobban, W.A., and Hook, S.C., 1988, Middle Cenomanian (Late Cretaceous) molluscan fauna from the base of the Boquillas Formation, Cerro de Muleros, Dona Ana County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin, v. 114, p. 35-44.

Kerr, P.F., Kulp, J.L., Patterson, C.M., and Wright, R.J., 1950, Hydrothermal alteration at Santa Rita, New Mexico: Geological Society of America Bulletin, v. 61, no. 4, p. 275-347.

Keyes, C.R., 1905, Geology and underground water conditions of the Jornada del Muerto: U.S. Geological Survey, Water Supply Paper 123, 42 p.

Kiely, J.M., 1987, Diagenesis and depositional setting of the Fanglomerate of Little Florida Mountains, southwestern New Mexico: El Paso, University of Texas, unpublished Master's thesis, 130 p.

Kiely, J.M., and James, W.C., 1988, Diagenesis of the fanglomerate of Little Florida Mountains (Miocene), southwestern New Mexico, *in* Mack, G.H., Lawton, T.F., and Lucas, S.G., eds., Cretaceous and Laramide tectonic evolution of southwestern New Mexico: New Mexico Geological Society, 39th Field Conference, Guidebook, p. 175-184.

Kilburn, J.E., Stoeser, D.B., Zimbelman, D.R., Hanna, W.F, and Gese, D.D., 1988, Mineral resources of the West Potrillo Mountains-Mount Riley and the Aden Lava Flow Wilderness Study Areas, Doña Ana and Luna Counties, New Mexico: U.S. Geological Survey Bulletin 1735-B, p. B1-B14.

King, P.B., King, R.E., and Knight, J.B., 1945, Geology of Hueco Mountains, El Paso and Hudspeth Counties, Texas: U.S. Geological Survey Oil and Gas Investigations Preliminary Map 36.

King, V.T., 1988, World news on mineral occurrences: Rocks and Minerals, v. 63, no. 4, p. 309-311.

King, W.E., 1973, Hydrogeology of La Mesa, Doña Ana County, New Mexico, *in* Hoffer, J.M., ed., The geology of southcentral Doña Ana County, New Mexico: El Paso Geological Society, 7th Annual Fieldguide, p. 56-67.

King, W.E., and Hawley, J.W., 1975, Geology and ground-water resources of the Las Cruces area, New Mexico, *in* Seager, W.R., Clemons, R.E., and Callender, J.F., eds., Guidebook of the Las Cruces Country: New Mexico Geological Society, 26th Annual Field Conference, p. 195-204.

King, W.E., Hawley, J.W., Taylor, A.M., and Wilson, R.P., 1971, Geology and ground-water resources of central and western Doña Ana County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Hydrologic Report 1, 64 p.

King, W.E., and Kelley, R.E., 1980, Geology and paleontology of Tortugas Mountain, Doña Ana County, New Mexico: New Mexico Geology, v. 2, p. 33-35.

Kingston, R.L., and Solomon, R.M., 1976, Erosion and sedimentation in the Upper Gila drainage, a case study: Hydrology and Water Resources of Arizona and the Southwest, v. 6, p. 103-111.

Kirkham, R.V., 1984, Sedimentary copper, *in* Eckstrand, O.R., ed., Canadian mineral deposit types--a geological synopsis: Geological Survey of Canada Economic Geology Report 36, p. 27.

Kirkham, R.V., and Sinclair, W.D., 1984a, Porphyry copper, molybdenum, tungsten, *in* Eckstrand, O.R., Canadian mineral deposit types--a geological synopsis: Geological Survey of Canada Economic Geology Report 36, p. 51-52.

Kirkham, R.V., and Sinclair, W.D., 1984b, Skarn copper, *in* Eckstrand, O.R., ed., Canadian mineral deposit types--a geological synopsis: Geological Survey of Canada Economic Geology Report 36, p. 58.

Kissin, S.A., 1988, The fire-element suite--Au indicator of non-magmatic ore types related to rifting and basin development, in The Geochemical Society, V. M. Goldschmidt Conference, Program and abstracts: University Park, PA., Pennsylvania State University, p. 52.

Kissin, S.A., 1993, Five-element (Ni-Co-As-Ag-Bi) veins, *in* Sheahan, P.A., and Cherry, M.E., eds., Ore deposit models, volume II: Geoscience Canada, Reprint Series 6, p. 87-98.

Klein, D.P., 1987, Aeromagnetic map of the Silver City 1°x2° quadrangle, New Mexico and Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map I-1310-D.

Klein, D.P., 1995, Structure of the basins and ranges, southwest New Mexico--An interpretation of seismic velocity sections: U.S. Geological Survey Open-File Report 95-506, 71 p., 2 plates.

Klein, D.P., and Johnson, G.R., 1983, Density, porosity, and magnetic properties of rock specimens from southwestern Arizona: U.S. Geological Survey Open-File Report 83-808, 31 p.

Klein, D.P., and Wynn, J.C., 1984, Density, porosity, and magnetic susceptibility of rocks from the Silver City 1°x2° quadrangle, New Mexico and Arizona: U.S. Geological Survey Open-File Report-84-0017, 13 p.

Kniffin, L.M., 1930, Mining engineering methods and costs of the Hanover Bessemer Iron and Copper Co., Fierro, New Mexico: U.S. Bureau of Mines Information Circular 6361, 21 p.

Kohn, P.A., and Dewey, C.P., 1990, Permian ostracodes from the upper Hueco Formation, Robledo Mountains, New Mexico: The Compass, v. 67, no. 4, p. 217-224.

Kolessar, J., 1970, Geology and copper deposits of the Tyrone district, *in* Woodward, L.A., ed., Guidebook of the Tyrone-Big Hatchet Mountains-Florida Mountains Region: New Mexico Geological Society, 21st Annual Field Conference, p. 127-132.

Kolessar, J., 1982, The Tyrone copper deposits, Grant county, New Mexico, *in* Titley, S.R., ed., Advances in geology of the porphyry copper deposits: University of Arizona Press, p. 327-333.

Kondelin, R.J., and LeMone, D.V., 1983, Ordovician rocks of Webb Gap area, north Franklins, Doña Ana County, New Mexico [abs.]: New Mexico Geology, v. 5, no. 3, p. 63.

Kool, J.B., Huyakorn, P.S., and Wierenga, P.J., 1990, Model calibration and simulation of flow in a heterogeneous soil, *in* Kovar, K., ed., ModelCARE 1990; Calibration and reliability in groundwater modelling: The Hague, September 3-6, 1990, IAHS-AISH Publication 195, p. 321-330.

Kool, J.B., and Parker, J.C., 1988, Effects of spatial variability on flow and transport in the unsaturated zone: EOS, Transactions of the American Geophysical Union, v. 69, no. 16, p. 352.

Kortemeier, C.P., 1982, Occurrence of Bishop Ash near Grama, New Mexico: New Mexico Geology, v. 4, no. 2, p. 22-24.

Kottlowski, F.E., 1953a, Road log, Alamogordo to Deming, New Mexico, along US-70: Roswell Geological Society, Guidebook 11th field conference, p. 99-116.

Kottlowski, F.E., 1953b, Road log from Las Cruces to Silver City, *in* Kottlowski, F.E., ed., Southwestern New Mexico: New Mexico Geological Society, 4th Annual Field Conference, Guidebook, p. 29-41.

Kottlowski, F.E., 1953c, Tertiary-Quaternary sediments of the Rio Grande valley in southern New Mexico, *in* Kottlowski, F.E., ed., Southwestern New Mexico: New Mexico Geological Society, 4th Annual Field Conference, Guidebook, p. 144-147.

Kottlowski, F.E., 1957, High-purity dolomite deposits of south-central New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 47, 43 p.
Kottlowski, F.E., 1958a, Geologic history of the Rio Grande near El Paso, *in* Nelson, L.A. and Haigh, B.R., leaders, Franklin and Hueco Mountains, Texas: West Texas Geological Society 1958 Fieldtrip Guidebook, p. 46-54.
Kottlowski, F.E., 1958b, Pennsylvanian and Permian rocks near the late Paleozoic Florida islands, *in* Hatchet Mountains and the Cookes Range-Florida Mountains area, Roswell Geological Society Guidebook to 11th field conference, p. 79-86.
Kottlowski, F.E., 1958c, Facets of the late Paleozoic strata in southwestern New Mexico; *in* Fitzsimmons, J.P., and Lochman-Balk, Christina, eds., Guidebook of southwestern New Mexico II: New Mexico Geological Society, 16th Field Conference, p. 141-147.
Kottlowski, F.E., 1959, Sedimentary rocks of the San Andres Mountains: Roswell Geological Society and Permian Basin Section, Society of Economic Paleontologists and Mineralogists Guidebook, Sacramento Mountains, p. 259-277.
Kottlowski, F.E., 1960a, Reconnaissance geologic map of Las Cruces 30-minute quadrangle: New Mexico Bureau of Mines and Mineral Resources Geologic Map 14, scale 1:26,720 (1" = 2 mi).
Kottlowski, F.E., 1960b, Summary of Pennsylvanian sections in southwest New Mexico and southeast Arizona: New Mexico Bureau of Mines and Mineral Resources Bulletin 66, 187 p.
Kottlowski, F.E., 1960c, Depositional features of the Pennsylvanian of south-central New Mexico: Roswell Geological Society Guidebook, Northern Franklin Mountains and southern San Andres Mountains, p. 96-130.
Kottlowski, F.E., 1962, Reconnaissance of commercial high-calcium limestones in New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 60, 77p.
Kottlowski, F.E., 1963, Paleozoic and Mesozoic strata of southwest and south-central New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 79, 100 p.
Kottlowski, F.E., 1965a, Middle Oligocene fluorite-barite mineralization in New Mexico [abs.]: Geological Society of America Program, Annual Meeting, p. 90.
Kottlowski, F.E., 1965b, Sedimentary basins of south-central and southwestern New Mexico: American Association of Petroleum Geologists Bulletin 49, no. 11, p. 2120-2139.
Kottlowski, F.E., 1965c, Talc, pyrophyllite, and ricolite, *in* Mineral and water resources of New Mexico: U.S. Congress, 89th, 1st session, Senate Committee on Interior and Insular Affairs (also New Mexico Bureau of Mines and Mineral Resources Bulletin 87), p. 296-298.
Kottlowski, F.E., 1971a, Paleozoic geologic history of southwest New Mexico and northern Chihuahua tectonic belt, *in* Seewald, K., and Sundeen, D., eds., The geologic framework of the Chihuahua tectonic belt: West Texas Geological Society, Publication 71-59, p. 25-37.
Kottlowski, F.E., 1971b, Petroleum potential of southwest New Mexico and south Arizona, *in* Future petroleum provinces of the United States--Their geology and potential: American Association of Petroleum Geologists Memoir 15, p. 431-448.
Kottlowski, F.E., 1973, Pre-Pliocene rocks in La Mesa region, southern Doña Ana County, New Mexico: El Paso Geological Society Guidebook, 7th field conference, p. 37-46.
Kottlowski, F.E., 1975, Stratigraphy of the San Andres Mountains in south central New Mexico, *in* Seager, W.R., Clemons, R.E., and Callender, J.F., eds., Guidebook of the Las Cruces Country; New Mexico Geological Society, 26th Annual Field Conference, p. 95-104.
Kottlowski, F. E., 1977, Talc, pyrophyllite, and ricolite, in Mineral and water resources of New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 87, p. 296-298.

Kottlowski, F.E., 1989, Paleozoic rocks between El Paso and the New Mexico-Arizona border, *in* Drewes, Harald, and Dyer, Russ, 1989, Tectonics of the eastern part of the Cordilleran Orogenic Belt, Chihuahua, New Mexico, and Arizona: Field Trip Guidebook T121, 28th International Geological Congress, Washington, D.C., American Geophysical Union, p. 71-74.

Kottlowski, F.E., Cooley, M.E., and Ruhe, R.V., 1965, Quaternary geology of the Southwest, *in* The Quaternary of the United States: Princeton, N.J., Princeton University Press, p. 287-298.

Kottlowski, F.E., Flower, R.H., Thompson, M.L., and Foster, R.W., 1956, Stratigraphic studies of the San Andres Mountains, New Mexico: New Mexico Bureau of Mines and Mineral Resources Memoir 1, 132 p.

Kottlowski, F.E., and Foster, R.W., 1960, Road log from Las Cruces to Hembrillo Canyon in San Andres Mountains, *in* Northern Franklin Mountains and Southern San Andres Mountains: Roswell Geological Society Guidebook, p. 35-72.

Kottlowski, F.E., and Foster, R.W., 1962, Pre-Tertiary strata of Tres Hermanas Mountains, Luna County, New Mexico: American Association of Petroleum Geologists Bulletin, v. 46, no. 11, p. 2090-2098.

Kottlowski, F.E., Foster, R.W., and Wengerd, S.A., 1969, Key oil tests and stratigraphic sections in southwest New Mexico, *in* Cordoba, D.A., Wengerd, S.A., and Shomaker, J., eds., Guidebook of the Border Region; Chihuahua and the United States: New Mexico Geological Society, 20th Annual Field Conference, p. 186-196.

Kottlowski, F.E., and LeMone, D.V., 1994, San Andres Mountains stratigraphy revisited, *in* Garber, R.A., and Keller, D.R., eds., Field guide to the Paleozoic section of the San Andres Mountains: 1994 Annual Field Trip Guidebook, Permian Basin Section-SEPM, PBS-SEPM Publication No. 94-35, p. 31-45.

Kottlowski, F.E., LeMone, D.V., and Foster, R.W., 1969, Early Ordovician highlands of Precambrian rocks and their associated facies: El Paso Geological Society, Guidebook to 3rd field conference, p. 134-142.

Kottlowski, F.E., LeMone, D.V., and Foster, R.W., 1973, Remnant mountains in Early Ordovician seas of the El Paso region, Texas and New Mexico: Geology, v. 1, p. 137-140.

Kottlowski, F.E., LeMone, D.V., and Seager, W.R., 1975, Marginal marine and continental facies of the Lower Permian in central New Mexico, *in* Permian exploration, boundaries, and stratigraphy: West Texas Geological Society and Permian Basin Section, Society of Economic Paleontologists and Mineralogists symposium volume, p. 119-124.

Kottlowski, F.E., and Pray, L.C., 1967, Silurian outcrops of south-central and southwestern New Mexico, *in* Symposium--Silurian-Devonian rocks of Oklahoma and environs: Tulsa Geological Society, Digest, v. 35, p. 209-230.

Kottlowski, F.E., Seager, W.R., Lemone, D.V., and Simpson, R.D., 1977, Abo-Hueco lithostrtigraphic relationships of south-central New Mexico and far West Texas [abs.]: Geological Society of America, Abstracts with Programs, v. 9, no. 1, p. 32-33.

Kottlowski, F.E., Weber, R.H., and Willard, M.E., 1969, Tertiary intrusive-volcanic-mineralization episodes in the New Mexico region [abs.]: Geological Society of America Annual Meeting Program, p. 278-279.

Kramer, W.V., 1970, Geology of the Bishop Cap hills, Doña Ana County, New Mexico: El Paso, University of Texas, unpublished Master's thesis, 76 p.

Krier, D.M., 1980, Geology of the southern part of the Gila Primitive Area, Grant County, New Mexico: Albuquerque, University of New Mexico, unpublished Master's thesis, 113 p.

Kuellmer, F.J., 1954, Geologic section of the Black Range at Kingston, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 33, 100 p.
Kuellmer, F.J., 1956, Geologic map of Hillsboro Peak 30-minute quadrangle: New Mexico Bureau of Mines and Mineral Resources Geologic Map 1, scale 1:126,720.
Kuellmer, F.J., and Kottlowski, F.E., 1965, Road log from Hillsboro to Mimbres Valley; *in* Fitzsimmons, J.P., and Lochman-Balk, Christina, eds., Guidebook of southwestern New Mexico II: New Mexico Geological Society, 16th Field Conference, p. 31-35.
Kudo, A.M., Aoki, K., and Brookins, D.G., 1971, The origin of Pliocene-Holocene basalts of New Mexico in the light of strontium-isotope and major-element abundances: Earth and Planetary Sciences Letters, v. 13, no. 1, p. 200-240.
Kues, B.S., 1986, Paleontology of the Caballero and Lake Valley formations (Lower Mississippian) west of the Rio Grande, south-central New Mexico, *in* Clemons, R.E., King, W., and Mack, G.H., eds., Truth or Consequences region: New Mexico Geological Society Guidebook; 37th annual field conference, p. 203-214.
Kuo, R.H., 1983, Seepage from irrigation canals in Mesilla Valley, New Mexico: Las Cruces, New Mexico State University, unpublished Ph. D. dissertation, 225 p..
Ladoo, R.B., 1923, Fluorspar mining in the western United States: U.S. Bureau of Mines Report of Investigation RI-2480, 35 p.
Ladoo, R.B., 1927, Fluorspar, its mining, milling, and utilization: U.S. Bureau of Mines Bulletin 244.
Lai, T.M., and Eberl, D.D., 1986, Controlled and renewable release of phosphorous in soils from mixtures of phosphate rock and NH_4-exchanged clinoptilolite: Zeolites, v. 6, p. 129-132.
Lamarre, A.L., and Hodder, R.W., 1978, Distribution and genesis of fluorite deposits in the western United States and their significance to metallogeny: Geology, v. 6, p. 236-238.
Lambert, M.F., 1984, A survey and excavation of caves in Hidalgo County, New Mexico: Santa Fe, New Mexico, School of American Research.
Lambert, R.S., 1973, Geology of the country east of the Santa Rita mining district, Grant County, New Mexico--The San Lorenzo area: Albuquerque, University of New Mexico, Master's thesis, 81 p.
Landon, R.E., 1929, Metamorphism and ore deposition in the Santa Rita-Hanover-Fierro area, New Mexico: Chicago, Ill., University of Chicago, unpublished Ph. D. dissertation, unknown p.
Lane, H.R., 1974, Mississippian of southeastern New Mexico and West Texas—A wedge–on–wedge relation: American Association of Petroleum Geologists Bulletin, v. 58, no. 2, p. 269–282.
Lanner, R.M., and VanDevender, T.R., 1981, Late Pleistocene piñon pines in the Chihuahuan Desert: Quaternary Research (New York), v. 15, no. 3, p. 278-290.
Larsh, P.A., 1911, Vanadium in old silver mines of New Mexico: Engineering and Mining Journal, June 24, p. 1248.
Larson, E.E., Patterson, P.E., Curtis, G., Drake, R., and Mutschler, F.E., 1985, Petrologic, paleomagnetic, and structural evidence of a Paleozoic rift system in Oklahoma, New Mexico, Colorado, and Utah: Geological Society of America Bulletin, v. 96, 1364-1372.
Lasky, S.G., 1930, Geology and ore deposits of the Ground Hog Mine, Central District, Grant County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 2, 14 p.
Lasky, S.G., 1935a, The Lordsburg district, New Mexico, *in* Copper resources of the world: 16th International Geological Congress, Washington, D.C., v. 1, p. 337-341.
Lasky, S.G., 1935b, Igneous assimilation and associated contact metamorphism in the Virginia mining district, New Mexico: American Mineralogist, v. 20, p. 552-561.

Lasky, S.G., 1936a, Hydrothermal leaching in the Virginia mining district, New Mexico: Economic Geology, v. 31, p. 156-169.
Lasky, S.G., 1936b, Geology and ore deposits of the Bayard area, Central mining district, New Mexico: U.S. Geological Survey Bulletin 870, 144 p.
Lasky, S.G., 1938a, Geology and ore deposits of the Lordsburg mining district, Hidalgo County, New Mexico: U.S. Geological Survey Bulletin 885, 62 p.
Lasky, S.G., 1938b, Outlook for further ore discoveries in the Little Hatchet Mountains, New Mexico: Economic Geology, v. 38, p. 365-389.
Lasky, S.G., 1940, Manganese deposits in the Little Florida Mountains, Luna County, New Mexico; a preliminary report: U.S. Geological Survey Bulletin 922-C, p. 55-73.
Lasky, S.G., 1947, Geology and ore deposits of the Little Hatchet Mountains, Hidalgo and Grant Counties, New Mexico: U.S. Geological Survey Professional Paper 208, 101 p.
Lasky, S.G., and Hoagland, A.D., 1948, Central mining district, New Mexico, *in* Symposium on the geology, paragenesis and reserves of the ores of lead and zinc: 18th International Geological Congress, London, p. 86-97.
Lasky, S.G., and Wootton, T.P., 1933, The metal resources of New Mexico and their economic features: New Mexico Bureau of Mines and Mineral Resources Bulletin 7, 178 p.
Laudon, L.R., and Bowsher, A.L., 1939, Stratigraphy of the Lake Valley formation of New Mexico: Geological Society of America Bulletin, v. 50, no. 12, pt. 2.
Laudon, L.R., and Bowsher, A.L., 1941, Mississippian formations of Sacramento Mountains, New Mexico: American Association of Petroleum Geologists Bulletin, v. 25, no. 12, p. 2107–2160.
Laudon, L.R., and Bowsher, A.L., 1949, Mississippian formations of southwestern New Mexico: Geological Society of America Bulletin, v. 60, 1-37.
Laughlin, A.W., Aldrich, M.J., and Vaniman, D.T., 1983, Tectonic implications of mid-Tertiary dikes in west-central New Mexico: Geology, v. 11, no. 1, p. 45-48.
Lawrence, V.A., 1986, Developments in the Cenozoic volcanic stratigraphy of the Indian Peaks area, northern Black Range, New Mexico, *in* Clemons, R.E., King, W.E., and Mack, G.H., eds., Truth or Consequences Region: New Mexico Geological Society, 37th Annual Field Conference, Guidebook, p. 179–182.
Lawrence, V.A., and Richter, D.H., 1986, Geologic map of the Indian Peaks West quadrangle, Catron County, New Mexico: U.S. Geological Survey Miscellaneous Field Studies sMap MF–1849, scale 1:24,000.
Lawton, T.F., Basbilvazo, G.T., Hodgson, S.A., Wilson, D.A., Mack, G.H., McIntosh, W.C., Lucas, S.G., and Kietzke, K.K., 1993, Laramide stratigraphy of the Little Hatchet Mountains, southwestern New Mexico: New Mexico Geology, v. 15, no. 1, p. 9-15.
Lawton, T.F., and Clemons, R.E., 1992, Klondike Basin—Late Laramide depocenter in southern New Mexico: New Mexico Geology, v. 14, no. 1, p. 1–7.
Leach, A.A., 1916, Black Hawk silver-cobalt ores: Engineering and Mining Journal, v. 102, p. 456.
Lee, W.T., 1905, The Engle coal field, New Mexico: U.S. Geological Survey Bulletin 285, p. 240.
Lee, W.T., 1907, Afton Craters of southern New Mexico: Geological Society of America Bulletin, v. 18, no. 5, p. 211-220.
Lee, W.T., 1909, Stratigraphy of the Manzano Group of the Rio Grande Valley, New Mexico: U.S. Geological Survey Bulletin 389, p. 5–40.
LeEng, Sheryl, 1992, Mineralogy, paragenesis, and elemental zoning of portions of the Pinos Altos skarn deposit, Grant County, New Mexico: Socorro, New Mexico Institute of Mining and Technology, unpublished Master's thesis, 83 p.

Lemly, I.S., 1982, The Lobo Formation and lithologically similar units in Luna and southwestern Doña Ana Counties, New Mexico: Las Cruces, New Mexico State University, unpublished Master's thesis, 95 p.

Lemmon, D.M., and Tweto, O.L., 1962, Tungsten in the United States: U.S. Geological Survey Mineral Resources Investigations Map MR-25.

LeMone, D.V., 1969a, Cambrian-Ordovician in El Paso Border Region, *in* Kottlowski, F.E., and LeMone, D.V., eds., Border Stratigraphy Symposium: New Mexico Bureau of Mines and Mineral Resources Circular 104, p. 17-25.

LeMone, D.V., 1969b, Ordovician type localities: El Paso Geological Society Annual Field Trip Guidebook 3--Ordovician symposium, p. 162.

LeMone, D.V., 1974, The Lower Ordovician Florida Mountains Formation stratotype, Luna County, New Mexico, *in* Corbitt, L.L., ed., Geology of the Florida Mountains, Luna County New Mexico: El Paso Geological Society, Guidebook 8, p. 36-46.

LeMone, D.V., 1976, General stratigraphy of the Franklin Mountains, *in* LeMone, D.V., and Lovejoy, E.M.P., eds., Symposium on the Franklin Mountains: El Paso Geological Society, p. 1-3.

LeMone, D.V., 1982a, Geology of the El Paso border region from the Tom Lea Park, El Paso, Texas, *in* Powers, R.B., ed., Geologic studies of the Cordilleran thrust belt: Rocky Mountain Association of Geologists, p. 889-892.

LeMone, D.V., 1982b, Geology of the El Paso border region from the Tom Lea Park, El Paso, Texas, *in* Drewes, H., ed., Cordilleran overthrust belt, Texas to Arizona, field conference: Denver, Colorado, Rocky Mountain Association of Geologists, p. 96-100.

LeMone, D.V., 1987, White Sands National Monument, New Mexico, *in* Beus, S.S., ed., The Decade of North American Geology Project series: Geological Society of America, DNAG, v. 6, p. 451-454.

LeMone, D.V., 1989, Geology of the Franklin Mountains, Texas, *in* Drewes, Harald, and Dyer, Russ, 1989, Tectonics of the eastern part of the Cordilleran Orogenic Belt, Chihuahua, New Mexico, and Arizona; Field Trip Guidebook T121, 28th International Geological Congress: Washington, D.C., American Geophysical Union, p. 8-11.

LeMone, D.V., and Flih, Baghdad, 1982, Waulsortian mounds of the Bishop Cap hills, Doña Ana County, New Mexico [abs.]: New Mexico Geology, v. 4, no. 1, p. 14.

LeMone, D.V., King, W.E., and Cunningham, J.E., 1974, Pennsylvanian System of Chloride Flat, Grant County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 131, 18 p.

LeMone, D.V., and Simpson, R.D., 1977, Paleoecological interpretations of Wolfcamp fossil communities in south-central New Mexico and far West Texas [abs.]: Geological Society of America Abstracts with Programs, v. 9, no. 1, p. 58.

LeMone, D.V., Simpson, R.D., and Kelment, K.W., 1975, Paleoecology of transition beds of Abo and upper members of Hueco Formation (lower Permian), southern New Mexico [abs.]: American Association of Petroleum Geologists Bulletin, v. 59, no. 5, p. 914-915.

Leonard, M.L., 1982, The geology of the Tres Hermanas Mountains, Luna County, New Mexico: El Paso, University of Texas, unpublished Master's thesis, 105 p.

Leopoldt, Winfried, 1981, Neogene geology of the central Mangas graben, Cliff-Gila area, Grant County, New Mexico: Albuquerque, University of New Mexico, unpublished Master's thesis, 160 p.

Leroy, P.G., 1951, Geology of the southern margin of the Santa Rita copper pit (New Mexico): New York, Columbia University, unpublished Master's thesis, unknown p.

Leroy, P.G., 1953, Correlation of copper mineralization with hydrothermal alteration in the Santa Rita porphyry copper deposit (New Mexico): New York, Columbia University, unpublished Ph. D. dissertation, unknown p.
Lesure, F.G., 1973, Feldspar, *in* Brobst, D.A., and Pratt, W.P., eds., United States mineral resources: U.S. Geological Survey Professional Paper 820, p. 217-222.
Leventhal, J.S., Hofstra, A.H., Vuletich, A.K., and Mancuso, T.B., 1987, Sediment-hosted disseminated gold mineralization at Jerritt Canyon, Nevada; vol. III, Role of organic matter [abs.]: Geological Society of America Abstracts with Programs, v. 19, no. 7, p. 745.
Lindberg, J.D., 1964, The peridot deposits of Kilbourne Hole, New Mexico: Lapidary Journal, v. 18, no. 7, p. 768-771.
Lindberg, J.D., 1984, Olivine, spinel, feldspar, and other curiosities from Riley Maar, New Mexico: Lapidary Journal, v. 38, no. 9, p. 1192-1196.
Lindberg, J.D., 1988, Rabb Canyon sanidine: Lapidary Journal, v. 42, no. 1, p. 39-40, 42-44.
Lindberg, J.D., and Douglass, R.E., 1976, The giant orange gypsum crystals in the White Sands National Monument: Lapidary Journal, v. 30, no. 4, p. 924-925.
Lindgren, W., 1909, The Tres Hermanas mining district, New Mexico: U.S. Geological Survey Bulletin 380, p. 123-128.
Lindgren, W., 1933, Mineral deposits (4th ed.): New York, McGraw-Hill Book Co., 930 p.
Lindgren, W., and Graton, L.C., 1906, A reconnaissance of the mineral deposits of New Mexico: U.S. Geological Survey Bulletin 285, p. 74-86.
Lindgren, W., Graton, L.C., and Gordon, C.H., 1910, The ore deposits of New Mexico: U.S. Geological Survey Professional Paper 68, 361 p.
Lindsey, D.A., Ganow, Harold, and Mountjoy, Wayne, 1973, Hydrothermal alteration associated with beryllium deposits at Spor Mountain, Utah: U.S. Geological Survey, Professional Paper 818-A,
Lindsey, D.A., and Shawe, D.R., 1982, Spor Mountain Be-F-U deposits, *in* Erickson, R.L., compiler, Characteristics of mineral deposit occurrences: U.S. Geological Survey, Open-File Report 82-795, p. 67-69.
Lipman, P.W., 1970, Relations between Cenozoic andesite and rhyolitic volcanism, western interior United States: Geological Society of London, Proceedings, no. 1662, p. 36-39.
Lipman, P.W., 1981, Volcano-tectonic setting of Tertiary ore deposits, southern Rocky Mountains, *in* Dickinson, W.R., and Payne, W.D., Relations of tectonics to ore deposits in the southern Cordillera: Arizona Geological Society Digest, v. 14, p. 199-214.
Lipman, P.W., 1984, The roots of ash flow calderas in western North America--Windows into the tops of granitic batholiths: Journal Geophysical Research, v. 89, no. B10, p. 8801-8841.
Lipman, P.W., and Mehnert, H.H., 1973, Late Cenozoic basaltic volcanism and development of the Rio Grande depression in the Southern Rocky Mountains [abs.]: Geological Society of America Abstracts with Programs, v. 5, no. 6, p. 493.
Lipman, P.W., Prostka, H.J., and Christiansen, R.L., 1972, Cenozoic volcanism and plate tectonic evolution of the western United States; part I--Early and Middle Cenozoic: Royal Society of London, Philosophical Transactions, v. 271, p. 217-248.
Lochman-Balk, C., 1958, The Capitol Dome section, Florida Mountains: Hatchet Mountains and Cooks Range-Florida Mountains area, Roswell Geological Society Guidebook 11, p. 47-52.
Logsdon, M.J., 1982, Gypsum resources of New Mexico, *in* Austin, G.S., compiler, Industrial rocks and minerals of the southwest: New Mexico Bureau of Mines and Mineral Resources Circular 182, p. 43-48.

Lohse, R.L., and Icerman, L., 1982a, An analysis of the geothermal potential of southwestern New Mexico, *in* Lacy, R.G., ed., Geothermal energy--Turn on the power!: Transactions Geothermal Resources Council, no. 6, p. 39-42.

Lohse, R.L., and Icerman, L., 1982b, Temperature gradient drilling in the Las Cruces East Mesa geothermal field, *in* Lacy, R.G., ed., Geothermal energy--Turn on the power!: Transactions Geothermal Resources Council, no. 6, p. 141-144.

Lohse, R.L., and Icerman, L., 1983, Temperature gradient drilling in the Mesquite-Anthony area, New Mexico, *in* Hunt, H.H., ed., Geothermal resources--Energy on tap!: Transactions Geothermal Resources Council, no. 7, p. 513-518.

Lohse, R.L., Schoenmackers, Rudi, Gross, Jim, and Whittier, Jack, 1985, Geothermal low-temperature reservoir assessment in Doña Ana County, New Mexico--Final report: Santa Fe: New Mexico Energy Research and Development Institute, NMERDI 2-71-4220, July 1985.

Long, K.R., 1995, Production and reserves of Cordilleran (Alaska to Chile) porphyry copper deposits; *in* Pierce, F.W., and Bolm, J.G., eds., Porphyry copper deposits of the American Cordillera: Arizona Geological Society Digest 20, p. 35-68.

Loring, A.K., and Armstrong, D.G., 1980, Cambrian-Ordovician syenites of New Mexico--Part of a regional alkalic intrusive episode: Geology, v. 8, 344-348.

Loring, A.K., and Loring, R.B., 1980a, Age of thrust faulting, Little Hatchet Mountains, southwestern New Mexico: Isochron/West, v. 27, p. 29-30.

Loring, A.K., and Loring, R.B., 1980b, K/Ar ages of middle Tertiary igneous rocks from southern New Mexico: New Mexico Bureau of Mines and Mineral Resources, Isochron/West, no. 28, p. 17-19.

Loucks, T.A., and Newell, R.A., 1978, Geology and alteration of the Chino North Pit, Santa Rita, New Mexico [abs.]: Geological Society of America Abstracts with Programs, v. 10, no. 3, p. 114.

Lovejoy, E.M.P., 1972, La estructura y tectonica intrusive del Cerro de Cristo Rey, Chihuahua, Mexico y Nuevo Mexico, Estados Unidos: Geological Society of Mexico, Convencion Nacionale, Memoir no. 2, p. 170-172.

Lovejoy, E.M.P., 1975a, An interpretation of the structural geology of the Franklin Mountains, Texas, *in* Seager, W.R., Clemons, R.E., and Callender, J.F., eds., Guidebook of the Las Cruces Country: New Mexico Geological Society, 26th Annual Field Conference, p. 261-268.

Lovejoy, E.M.P., 1975b, Cenozoic tectonics of the El Paso, Texas, region, *in* Exploration from the Mountains to the basin: Transactions, Joint meeting, Southwest Section, American Association of Petroleum Geologists and Permian Basin Section, Society of Economic Paleontologists and Mineralogists, El Paso, Texas, p. 95-99.

Lovejoy, E.M.P., 1976a, Geology of Cerro de Cristo Rey Uplift, Chihuahua and New Mexico: New Mexico Bureau of Mines and Mineral Resources Memoir 31, p. 84.

Lovejoy, E.M.P., 1976b, A little problem concerning Fort Hancock-Camp Rice "mixed rounded gravels"; correlation in the El Paso-Las Cruces regions, as viewed by a skeptic, *in* LeMone, D.V., and Lovejoy, E.M.P., eds., Symposium on the Franklin Mountains: El Paso Geological Society Quinn Memorial Volume, p. 99-104.

Lovejoy, E.M.P., 1976c, Neotectonics of the southeast end of the Rio Grande rift along Mesilla Valley fault zone, and the course of the Rio Grande, El Paso, Texas, *in* LeMone, D.V., and Lovejoy, E.M.P., Symposium on the Franklin Mountains: El Paso Geological Society Quinn Memorial Volume, p. 139-148.

Lovejoy, E.M.P., and Hawley, J.W., 1978, Southern rift guide 1, El Paso, Texas-Socorro, New Mexico--El Paso to New Mexico-Texas State line, *in* Hawley, J.W., compiler, Guidebook

to Rio Grande rift in New Mexico and Colorado: New Mexico Bureau of Mines and Mineral Resources Circular 163, p. 57-67.
Lovejoy, E.M.P., and Seager, W.R., 1978, Discussion of structural geology of Franklin Mountains, *in* Hawley, J.W., compiler, Guidebook to Rio Grande rift in New Mexico and Colorado: New Mexico Bureau of Mines and Mineral Resources Circular 163, p. 68-69.
Lovering, T.G., 1956, Radioactive deposits in New Mexico: U.S. Geological Survey, Bulletin 1009-L, p. 315-390.
Lovering, T.G., and Hedal, J.A., 1987, Trace elements in magnetic concentrates from stream sediments in southwestern New Mexico--A potential tool for reconnaissance geochemical exploration in arid lands: U.S. Geological Survey Bulletin 1566, 31 p.
Lowell, J.D., 1974, Regional characteristics of porphyry copper deposits of the southwest: Economic Geology, v. 69, no. 5, p. 601-617.
Lowman, P.D., Jr., 1969, Apollo 9 multispectral photography; geologic analysis: Greenbelt, Md., Goddard Space Flight Center, Report X-644-69-423, 53 p.
Lozinsly, R.P., 1986, Geology and late Cenozoic history of the Elephant Butte area, Sierra County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 187, 40 p.
Lozinsky, R.P., and Hawley, J.W., 1986, The Palomas Formation of south–central New Mexico––A formal definition: New Mexico Geology, v. 8, no. 4, p. 73–78, 82.
Lucas, S.G., 1986, Oligocene mammals from the Black Range, southwestern New Mexico, *in* Clemons, R.E., King, W.E., and Mack, G.H., eds., Truth or Consequences region: New Mexico Geological Society, 37th Field Conference, Guidebook, p. 261-263.
Lucas, S.G., 1988, The "Deming Dinosaur" was a mammoth, *in* Mack, G.H., Lawton, T.F., and Lucas, S.G., eds., Cretaceous and Laramide tectonic evolution of southwestern New Mexico: New Mexico Geological Society, 39th Field Conference, Guidebook, p. 12-13.
Lucas, S.G., 1993, Geological context of Permian tracksite, Robledo Mountains, Doña Ana County, New Mexico: New Mexico Geological Society Spring Meeting, Proceedings, p. 40.
Lucas, S.G., Basabilvazo, G., and Lawton, T.F., 1990, Late Cretaceous dinosaurs from the Ringbone Formation, southwestern New Mexico, USA: Cretaceous Research, v. 11, no. 4, p. 343-349.
Lucas, S.G., Hunt, A.P., and Pence, R., 1988, Some Late Cretaceous reptiles from New Mexico, *in* Wolberg, D.L., ed., Contributions to Late Cretaceous paleontology and stratigraphy of New Mexico--Part III: New Mexico Bureau of Mines and Mineral Resources Bulletin 122, 122 p.
Lucas, S.G., Kues, B.S., Hayden, S.N., Allen, B.D., Kietzke, K.K., Williamson, T.W., Sealey, Paul, and Pence, Randy, 1988, Cretaceous stratigraphy and biostratigraphy, Cooke's Range, Luna County, New Mexico, *in* Mack, G.H., Lawton, T.F., and Lucas, S.G., eds., Cretaceous and Laramide tectonic evolution of southwestern New Mexico: New Mexico Geological Society, 39th Annual Field Conference, Guidebook, p. 143-167.
Lucas, S.G., Williamson, T.E., and Hunt, A.P., 1989, Cretaceous stratigraphy near Virden, Hidalgo County, New Mexico [abs.]: New Mexico Geology, v. 11, no. 2, May 1989, p. 40.
Ludington, S.D., 1974, Application of fluorite-hydroxyl exchange data to natural minerals: University of Colorado, unpublished Ph. D. dissertation, 177 p.
Ludington, S.D., Hanna, W.R., Turner, R.L., and Jeske, R.E., 1988, Mineral Resources of the Organ Mountains Wilderness Study Area, Doña Ana County, New Mexico: U.S. Geological Survey Bulletin 1735-D, p. D1-D17.
Ludington, S.D., Orris, G.J., Cox, D.P., Long, K.R., and Asher-Bolinder, Sigrid, 1992, Mineral deposit models, *in* U.S. Geological Survey and Servico Geologico de Bolivia, Geology and

mineral resources of the Altoplano and Cordillera Occidental, Bolivia: U.S. Geological Survey Bulletin 1975, p. 63-89.
Luedke, R.G., 1993, Maps showing distribution, composition, and age of middle Cenozoic volcanic centers in Arizona, New Mexico, and west Texas: U.S. Geological Survey Miscellaneous Investigations Series Map I-2291-A, scale 1:1,000,000, 2 sheets, text.
Luedke, R.G., and Smith, R.L., 1978, Map showing distribution, composition, and age of Late Cenozoic volcanic centers in Arizona and New Mexico: U.S. Geological Survey Miscellaneous Investigations Series Map I-1091-A, scale 1:1,000,000.
Lueth, V.W., 1984, Comparison of copper skarn deposits in the Silver City mining region, southwestern New Mexico: El Paso, University of Texas, unpublished Master's thesis, unknown p.
Lueth, V.W., 1988, Studies of the geochemistry of the semi-metal elements--arsenic, antimony, and bismuth: El Paso, University of Texas, unpublished Ph. D. dissertation, 107 p.
Lueth, V.W., 1995, Garnet resource potential in southern New Mexico; *in* Proceedings of the 31st forum on the geology of industrial minerals: New Mexico Bureau of Mines and Mineral Resources, Bulletin 154.
Lueth, V.W., Goodell, P.C., Llavona, Ramon, Mertig, Heidi, and Sharp, William, 1987, Tellurium minerals of the Organ District, Doña Ana County, New Mexico: 8th Annual New Mexico Mineral Symposium, Proceedings, p. 17.
Lueth, V.W., Goodell, P.C., Llavona, Ramon, and Sandoval, Juan, 1988a, Inclusions in galena from the Organ District, Doña Ana County, New Mexico [abs.]: 9th Annual New Mexico Mineral Symposium, Proceedings, p. 19.
Lueth, V.W., Goodell, P.C., Llavona, Ramon, and Sandoval, Juan, 1988b, Compositional variations and mineral inclusions in galena from the Organ District, Doña Ana County, New Mexico [abs.]: New Mexico Geology, v. 11, no. 2, p. 38-39.
Lufkin, J.L., 1972, Tin mineralization within rhyolite flow-domes (Tertiary), Black Range, New Mexico: Palo Alto, California, Stanford University, unpublished Ph. D. dissertation, 227 p.
Lufkin, J.L., 1976, Oxide minerals in miarolitic rhyolite, Black Range, New Mexico: American Mineralogist, v. 61, nos. 5-6, p. 425-430.
Lydon, J.W., Franklin, J.M., and Sangster, D.F., 1984, Volcanic-associated massive sulfide, *in* Eckstrand, O.R., ed., Canadian mineral deposit types--a geologic synopsis: Geological Survey of Canada Economic Geology Report 36, p. 33-34.
Lynn, G.C., 1975, Stratigraphic correlation of the El Paso and Montoya Groups in the Victorio Mountains, the Snake Hills, and the Big Florida Mountains in southwestern New Mexico: Tucson, University of Arizona, unpublished Master's thesis, 115 p.
Macer, R.J., 1978, Fluid inclusion studies of fluorite around the Organ cauldron, Doña Ana County, New Mexico: El Paso, University of Texas, unpublished Master's thesis, 107 p.
Machette, M.N., 1978a, Preliminary geologic map of the Socorro 1°x2°quadrangle, central New Mexico: U.S. Geological Survey Open–File Report 78–0607, scale 1:250,000.
Machette, M.N., 1978b, Geologic map of the Acacia quadrangle, Socorro County, New Mexico: U.S. Geological Survey Geologic Quadrangle Map GQ–1415, scale 1:24,000.
Machette, M.N., 1982, Morphology, age, and rate of accumulation of pedogenic $CaCO_3$ in some calcareous soils and pedogenic calcretes of southwestern United States [abs.]: Geological Society of America Abstracts with Programs, v. 14, no. 4, p. 182-183.
Machette, M.N., 1985, Calcic soils of the southwestern United States; Soils and Quaternary geology of the southwestern United States: Geological Society of America Special Paper 203, p. 1-21.

Machette, M.N., 1987, Preliminary assessment of paleoseismicity at White Sands Missile Range, southern New Mexico; evidence for recency of faulting, fault segmentation, and repeat intervals for major earthquakes in the region: U.S. Geological Survey Open-File Report 87-0444, 46 p.

Machette, M.N., Personius, S.F., Menges, C.M., and Pearthree, P.A., 1986, Map showing Quaternary and Pliocene faults in the Silver City 1°x2° quadrangle and the Douglas 1°x2° quadrangle, southeastern Arizona and southwestern New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map MF-1465-C.

Mack, G.H., 1986, Lower Cretaceous stratigraphy and depositional environments in the East Potrillo Mountains and adjacent areas of southwestern New Mexico, *in* Hoffer, J.M., ed., Geology of southcentral New Mexico: El Paso Geological Society Guidebook, p. 85-94.

Mack, G.H., 1987a, Mid-Cretaceous (late Albian) change from rift to retro-arc foreland basin in southwestern New Mexico: Geological Society of America Bulletin, v. 98, no. 5, p. 507-514.

Mack, G.H., 1987b, Tectonic, eustatic, and climate control on Cretaceous (Aptian to Turonian) sedimentation in southwestern New Mexico, *in* Dickinson, W.R., and Klute, M.A., eds., Mesozoic rocks of southern Arizona and adjacent areas: Arizona Geological Society, Digest, v. 18, p. 371-379.

Mack, G.H., and Clemons, R.E., 1988, Structural and stratigraphic evidence for the Laramide (early Tertiary) Burro Uplift in southwestern New Mexico, *in* Mack, G.H., Lawton, T.F., and Lucas, S.G., eds., Cretaceous and Laramide tectonic evolution of southwestern New Mexico: New Mexico Geological Society, 39th Field Conference, Guidebook, p. 58-66.

Mack, G.H., Clemons, R.E., and Seager, W.R., 1983, Paleogene sandstone petrofacies in south-central New Mexico; evidence for change from Laramide deformation to volcanism [abs.]: Abstracts with Programs, Geological Society of America Bulletin 15, no. 6, p. 633.

Mack, G.H., Galemore, J.A., and Kaczmarek, E.L., 1988, The Cretaceous foreland basin in southwestern New Mexico, *in* Mack, G.H., Lawton, T.F., and Lucas, S.G., eds., Cretaceous and Laramide tectonic evolution of southwestern New Mexico: New Mexico Geological Society, 39th Annual Field Conference, Guidebook, p. 135-142.

Mack, G.H., and Grigsby, J.D., 1985, Mechanical and chemical diagenesis of the Hayner Ranch and Rincon Valley formations (Santa Fe Group, Miocene), San Diego Mountain, New Mexico: New Mexico Geology, v. 7, no. 3, p. 45-48.

Mack, G.H., and James, W.C., 1986, Cyclic sedimentation in the mixed siliciclastic-carbonate Abo-Hueco transitional zone (Lower Permian), southwestern New Mexico: Journal of Sedimentary Petrology, v. 56, no. 5, p. 635-647.

Mack, G.H., James, W.C., and Seager, W.R., 1988, Wolfcampian stratigraphy and depositional environments in the Doña Ana Mountains, south-central New Mexico, *in* Basin to shelf facies transition of the Wolfcampinan stratigraphy of the Orogrande Basin: Permian Basin Section, Society of Economic Paleontologists and Mineralogists Publication 88-28, p. 97-106.

Mack, G.H., Kolins, W.B., and Galemore, J.A., 1986, Lower Cretaceous stratigraphy, depositional environments, and sediment dispersal in southwestern New Mexico: American Journal of Science, v. 286, no. 4, p. 309-331.

Mack, G.H., and Seager, W.R., 1988, Laramide block uplifts and complementary basins in southwestern New Mexico [abs.]: American Association of Petroleum Geologists Bulletin, v. 72, no.1, p. 101.

Mack, G.H., and Seager, W.R., 1990, Tectonic control on facies distribution of the Camp Rice and Palomas formations (Pliocene-Pleistocene) in the southern Rio Grande Rift: Geological Society of America Bulletin, v. 102, no. 1, p. 45-53.

Mack, G.H., and Seager, W.R., 1995, Transfer zones in the southern Rio Grande Rift: Journal of the Geological Society of London, v. 152, Pt. 3, p. 551-560.
Mack, G.H., Seager, W.R., and Kieling, John, 1994, Late Oligocene and Miocene faulting and sedimentation, and evolution of the southern Rio Grande rift, New Mexico, U.S.A.: Sedimentary Geology, v. 92, nos. 1-2, p. 79-96.
Mack, P.D.C., 1985, Correlation and provenance of facies within the upper Santa Fe Group in the subsurface of the Mesilla Valley, southern New Mexico: Las Cruces, New Mexico State University, unpublished Master's thesis, 137 p.
Madden, H.D., and LeMone, D.V., 1983, Stratigraphy and regional relationships of Mississippian system north Franklin Mountains, Doña Ana County, south-central New Mexico [abs.]: New Mexico Geology, v. 5, no. 3, p. 64.
Madrosian, C.A., 1977, Mining districts and mineral deposits of New Mexico: New Mexico Bureau of Mines and Mineral Resources, scale 1:1,000,000.
Magee, R.W., Moore, J.M., and Brunner, J., 1987, Thematic mapper data applied to mapping hydrothermal alteration in southwest New Mexico, *in* Cook, J.J., and Rogers, R.H., eds., Proceedings of the Fifth thematic conference on Remote Sensing for Exploration Geology; mineral and energy exploration--Technology for a competitive world: Ann Arbor, Michigan, Environmental Research Institute, v. 1, p. 373-382.
Maggiore, Peter, 1981, Deformation and metamorphism on the floor of a major ash-flow tuff cauldron--The Emory cauldron, Grant and Sierra Counties, New Mexico: Albuquerque, University of New Mexico, unpublished Master's thesis, 133 p.
Martin, G.A., 1908, Sylvanite, New Mexico: Engineering and Mining Journal, v. 86, no. 12, p. 962-963.
Marvin, R.F., and Cole, J.C., 1978, Radiometric ages; compilation A, U.S. Geological Survey: Isochron West, v. 22, p. 3–14.
Marvin, R.F., and Dobson, S.W., 1979, Radiometric ages: compilation B; U.S. Geological Survey: Isochron/West, no. 26, p. 3-32.
Marvin, R.F., Mahnert, H.H., and Naeser, C.W., 1988, U.S. Geological Survey radiometric ages, compilation C, part 2 --Arizona and New Mexico: Isochron/West, v. 51, p. 5-13.
Marvin, R. F., and Dobson, S. W., 1979, Radiometric ages: compilation B, U.S. Geological Survey: Isochron/West, no. 26, pp. 3-32.
Marvin, R.F., Mehnert, H.H., and Naeser, C.W., 1988, U.S. Geological Survey radiometric ages—compilation "C", Pt. 2; Arizona and New Mexico: Isochron/West, no. 51, p. 5-13.
Marvin, R.F., Naeser, C.W., Bikerman, M., Mehnert, H.H., and Ratté, J.C., 1987, Isotopic ages of post-Paleocene igneous rocks within and bordering the Clifton 1°x2° quadrangle, Arizona-New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 118, 63 p.
Marvin, R.F., Naeser, C.W., and Mehnert, H.H., 1978, Tabulation of radiometric ages, including unpublished K-Ar and fission-track, for rocks in southeastern Arizona and southwestern New Mexico, *in* Callender, J.F., Wilt, J.C., Clemons, R.E., and James, H.L., eds., Land of Cochise, southeastern Arizona: New Mexico Geological Society, 29th Annual Field Conference, Guidebook, p. 243-252.
Matchus, E.J., 1985, The 1984 east-west cross section through the Permian Basin of West Texas: West Texas Geological Society Bulletin 24, no. 5, p. 19.
Matheney, R.K., and Brookins, D.G., 1983, Geochronologic studies of igneous rocks from Florida Mountains, New Mexico [abs.]: New Mexico Geology, v. 5, no. 3, p. 67.
Matheney, R.K., and Brookins, D.B., 1989, Two models for resetting of Rb-Sr isochron dates of Cambrian red-rock granophyres, Florida Mountains, New Mexico; A test using oxygen isotopes [abs.]: Geological Society of America Abstracts with Programs, v. 21, no. 5, p. 112.

Matheney, R.K., Brookins, D.G., Wallin, E.T., Shafiqullah, M., and Damon, P.E., 1990, Incompletely reset Rb-Sr systems from a Cambrian red-rock granophyre terrane, Florida Mountains, New Mexico, USA: Chemical Geology, Isotope Geoscience Section, v. 86, no. 1, p. 29-47.

Matheney, R.K., Shafiqullah, M., Brookins, D.G., Damon, P.E., and Wallin, E.T., 1988, Geochronologic studies of the Florida Mountains, New Mexico, *in* Mack, G.H., Lawton, T.F., and Lucas, S.G., eds., Cretaceous and Laramide tectonic evolution of southwestern New Mexico: New Mexico Geological Society, 39th Field Conference, Guidebook, p. 99-107.

Mathez, E.A., Blacic, J.D., Beery, J., Maggiore, C., and Hollander, M., 1984, Carbon abundances in mantle minerals determined by nuclear reaction analysis: Geophysical Research Letters, v. 11, no. 10, p. 947-950.

Maxwell, C.H., and Oakman, M.R., 1990, Geologic map of the Cuchillo quadrangle, Sierra County, New Mexico: U.S. Geological Survey Geologic Quadrangle Map GQ–1686, scale 1:24,000.

Maxwell, C.H., Foord, E.E., Oakman, M.R., and Harvey, D.B., 1986, Tin deposits in the Black Range tin district, *in* Clemons, R.E., King, W.E., and Mack, G.H., eds., Truth or Consequences region: New Mexico Geological Society, 37th Field Conference, Guidebook, p. 273-281.

May, R.J., and Machette, M.N., 1984, Thermoluminescence dating of soil carbonate: U.S. Geological Survey Open-File Report 84-0083, 25 p.

May, R.T., Smith, E.S., Dickson, R.E., and Nystrom, R.J., 1982, Douglas quadrangle, Arizona and New Mexico: Bendix Field Engineering Corporation, Grand Junction Operations, Report PGJ/F-118(82), 78 p.

Mayer, L., McFadden, L.D., and Harden, J.W., 1988, Distribution of calcium carbonate in desert soils--A model: Geology, v. 16, no. 4, p. 303-306.

Maynard, J.B., and Van Houten, F.B., 1991, Descriptive model of oolitic ironstones, *in* Bliss, J.D., ed., Developments in mineral deposit modeling: U.S. Geological Survey Bulletin 2004, p. 39-40.

Mayo, E.B., 1958, Lineament tectonics and some ore districts of the southwest: Mining Engineering, v. 11, p. 1169-1175.

McAnulty, W.N., 1972a, Fluorspar in silicified rocks in New Mexico: New Mexico Bureau of Mines and Mineral Resources Target Exploration Report E-7, 3 p.

McAnulty, W.N., 1972b, Winkler Anticline fluorspar, Hidalgo County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Target Exploration Report E-3, 7 p.

McAnulty, W.N., 1974, Fluorspar in New Mexico, *in* Siemers, C.T., ed., Silver Anniversary Guidebook--Ghost Ranch, Central-northern New Mexico; Base metal and fluorspar districts of New Mexico--a symposium: New Mexico Geological Society, 25th Field Conference, Guidebook, p. 382.

McAnulty, W.N., 1978, Fluorspar in New Mexico: New Mexico Bureau of Mines and Mineral Resources Memoir 34, 64 p.

McCaslin, J.C., 1984, ARCO plans remote New Mexico wildcat: Oil and Gas Journal, v. 82, no 53, p. 177-178.

McClannahan, K.M., 1984, Paleomagnetic investigation of mid-Tertiary rocks from the Mogollon-Datil volcanic field, southwestern New Mexico: Houghton, Michigan Technological University, Master's thesis, 65 p.

McCullar, D.B., and Smithson, S.B., 1977, Unreversed seismic crustal refraction profile across the southern Rio Grande Rift: EOS, American Geophysical Union Transactions, v. 58, no. 12, p. 1184.

McDanal, S.K., Forn, C.L., Hassemer, J.R., and Watts, K.C., 1983, Analytical results for stream-sediment concentrate, sieved stream-sediment, rock, and water samples from the Silver City 1°x2° quadrangle, New Mexico and Arizona: U.S. Geological Survey Report; available only through NTIS, PB-83-220-863.

McDowell, F.W., 1971, K-Ar ages of igneous rocks from the western United States: Isochron/West, no. 2, p. 1-16.

McEvers, Lloyd, and LeMone, D.V., 1983, Fusselman Dolomite of north Franklin Mountains, Doña Ana County, New Mexico [abs.]: New Mexico Geology, v. 5, no. 3, p. 64.

McHugh, J.B., Miller, W.R., and Ficklin, W.H., 1983, Analytical results for 26 water samples from southern New Mexico: U.S. Geological Survey Open-File Report 83-0777, 3 tables.

McIntosh, W.C., 1989, Timing and distribution of ignimbrite volcanism in the Eocene-Miocene Mogollon-Datil volcanic field, *in* Chapin, C.E., and Zidek, Jiri, eds., Field excursions to volcanic terranes in the western United States, vol. I--Southern Rocky Mountain region: New Mexico Bureau of Mines and Mineral Resources Memoir 46, p. 58-230.

McIntosh, W.C., 1991, Evaluation of paleomagnetism as a correlation criterion for Mogollon-Datil ignimbrites, southwestern New Mexico: Journal of Geophysical Research, v. 96, no. 8, p. 13,459-13,483.

McIntosh, W.C., Chapin, C.E., and Geissman, J.W., 1991, Stratigraphic framework for Eocene-Oligocene ignimbrites in the southwestern corner of New Mexico [abs.]: Geological Society of America Abstracts with Programs, v. 23, no. 4, p. 47.

McIntosh, W.C., Chapin, C.E., Ratté, J.C., and Sutter, J.F., 1992, Time-stratigraphic framework for the Eocene-Oligocene Mogollon-Datil volcanic field, southwest New Mexico: Geological Society of America Bulletin, v. 104, p. 851-871.

McIntosh, W.C., Kedzie, L.L., and Sutter, J.F., 1991, Paleomagnetism and $^{40}Ar/^{39}Ar$ ages of ignimbrites, Mogollon-Datil volcanic field, southwest New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 135, 70 p.

McIntosh, W.C., Sutter, J.F., Chapin, C.E., and Kedzie, L.L., 1990, High-precision $^{40}Ar/^{39}Ar$ sanidine geochronology of ignimbrites in the Datil-Mogollon volcanic field, southwestern New Mexico: Bulletin of Volcanology, v. 52, p. 584-601.

McIntyre, D.H., 1988, Volcanic geology in parts of the southern Peloncillo Mountains, Arizona and New Mexico: U.S. Geological Survey Bulletin 1671, 18 p.

McKee, E.D., and Moiola, R.J., 1975, Geometry and growth of the White Sands dune field, New Mexico: U.S. Geological Survey Journal of Research, v. 3, no. 1, p. 59-66.

McKee, E.H., and Noble, D.C., 1974, Timing of crustal extension in the western United States [abs.]: Geological Society of America Abstracts with Programs, v. 6, no. 3, p. 218.

McKnight, J.F., and Fellows, M.L., 1978, Silicate mineral assemblages and their relationship to sulfide mineralization, Pinos Altos mineral deposit, New Mexico, *in* Jenney, J.P., and Hauck, H.R., eds., Proceedings of the porphyry copper symposium: Arizona Geological Society Digest, v. 11, p. 1-8.

McLean, J.S., 1970, Saline ground-water resources of the Tularosa Basin, New Mexico: U.S. Geological Survey Open-File Report, 128 p.

McLean, J.S., 1975, Saline ground water in the Tularosa Basin, New Mexico, *in* Seager, W.R., Clemons, R.E., and Callender, J.F., eds., Guidebook of the Las Cruces Country: New Mexico Geological Society, 26th Annual Field Conference, p. 237-238.

McLean, J.S., 1977, Hydrologic maps and data in the Mimbres Basin, New Mexico: U.S. Geological Survey Open-File Report 77-314, 531 p., scale 1:48,000.

McLemore, V.T., 1982, Radioactive occurrences in veins and igneous and metamorphic rocks of New Mexico with annotated bibliographic: New Mexico Bureau of Mines and Mineral Resources Open File Report 155, 267 p.

McLemore, V.T., 1983a, Uranium industry in New Mexico; history, production, and present status: New Mexico Geology, v. 5, no. 3, p. 45-51.
McLemore, V.T., 1983b, Uranium and thorium occurrences in New Mexico--Distribution, geology, production, and resources, with selected bibliography: New Mexico Bureau of Mines and Mineral Resources Open File Report 183, 180 p.
McLemore, V.T., 1988, Copper, gold, silver, lead and zinc production in Doña Ana, southern Grant, Hidalgo and Luna Counties, New Mexico, *in* Mack, G.H., Lawton, T.F., and Lucas, S.G., eds., Cretaceous and Laramide tectonic evolution of southwestern New Mexico: Deming, N. Mex., New Mexico Geological Society, 39th Annual Field Conference, Guidebook, p. 199-201.
McLemore, V.T., 1992, Uranium occurrences in the Chihuahua Desert area, Sierra, Grant, Hidalgo, Luna, and Dona Ana Counties, New Mexico, *in* Goodell, P.C., Gutierrez, C.G., and Cortes, I.R., eds., Energy Resources of the Chihuahua Desert Region: Department of Geological Sciences, University of Texas at El Paso, p. 224-232.
McLemore, V.T., 1993a [1994], Geology and geochemistry of the mineralization and alteration in the Steeple Rock District, Grant County, New Mexico and Greenlee County, Arizona: El Paso, University of Texas, Ph. D. dissertation, 499 p. (also New Mexico Bureau of Mines and Mineral Resources Open File Report 397).
McLemore, V.T., 1993b, Geology and geochemistry of the mineralization and alteration in the Steeple Rock district, Grant County, New Mexico and Greenlee County, Arizona. El Paso, University of Texas, Ph. D dissertation, 525 p. (NMBMMR Open-file report 397).
McLemore, V.T., 1994a, Summary of the mineral resources in the San Andres and Organ Mountains, south-central New Mexico, *in* Garber, R.A., and Keller, D.R., eds., Field guide to the Paleozoic section of the San Andres Mountains: 1994 Annual Field Trip Guidebook, Permian Basin Section -SEPM, PBS-SEPM Publication No. 94-35, p. 143-153.
McLemore, V.T., 1994b, Placer gold deposits in New Mexico: New Mexico Geology, v. 16, p. 21-25.
McLemore, V.T., 1994c, Geology and zoning in the Steeple Rock District, New Mexico and Arizona: AIME/SME, Preprint 94-64, 11 p.
McLemore, V.T., 1996a (in press), Volcanic-epithermal precious-metal deposits in New Mexico, *in* Geology and ore deposits of the American Cordillera: Geological Society of Nevada.
McLemore, V.T., 1996b (in press), Silver and gold occurrences in New Mexico: New Mexico Bureau of Mines and Mineral Resources, Resource Map 21, scale 1:1,000,000.
McLemore, V.T., and Barker, J.M., 1985, Barite in north-central New Mexico: New Mexico Geology, v. 7, no. 2, p. 21-25.
McLemore, V.T., and Chamberlin, R.M., 1986, National Uranium Resource Evaluation (NURE) data available from the New Mexico Bureau of Mines and Mineral Resources: New Mexico Bureau of Mines and Mineral Resources pamphlet, 22 p.
McLemore, V.T., and Chenoweth, W.L., 1989, Uranium resources in New Mexico: New Mexico Bureau of Mines and Mineral Resources Resource Map 18, 36 p.
McLemore, V.T., and Clark, K.R., 1993, Alteration and epithermal mineralization int he Steepl e Rock mining district, Grant County, New Mexico and Greenlee County, Arizona [abs.], Conference Program and extended abstracts, Integrated Methods in Exploration and Discovery, Society of Economic Geologists, p. AB 69-70.
McLemore, V.T., and Lueth, V.W., 1995, Carbonate-hosted lead-zinc deposits in New Mexico: International Conference on Carbonate-Hosted Lead-Zinc Deposits [abs.]: Extended abstracts, Society of Economic Geologists, p. 209-211.

McLemore, V.T., and Lueth, V.W., 1996 (in press), Lead-zinc deposits in carbonate rocks in New Mexico: Economic Geology.

McLemore, V.T., McIntosh, W.C., and Pease, T.C., 1995, $^{40}Ar/^{39}Ar$ age determinations of four plutons associated with mineral deposits in southwestern New Mexico: New Mexico Bureau of Mines and Mineral Resources Open File Report 410.

McLemore, V.T., and McKee, C., 1988a, A preliminary geochemical study of the Redrock anorthosite and granite, Burro Mountains, southwestern New Mexico, *in* Mack, G.H., Lawton, T.F., and Lucas, S.G., eds., Cretaceous and Laramide tectonic evolution of southwestern New Mexico: Deming, N. Mex., New Mexico Geological Society, 39th Annual Field Conference, Guidebook, p. 82-88.

McLemore, V.T., and McKee, C., 1988b, Geochemistry of the Burro Mountains syenites and adjacent Proterozoic granite and gneiss and the relationship to a Cambrian-Ordovician alkalic magmatic event in New Mexico and southern Colorado, *in* Mack, G.H., Lawton, T.F., and Lucas, S.G., eds., Cretaceous and Laramide tectonic evolution of southwestern New Mexico: Deming, N. Mex., New Mexico Geological Society, 39th Annual Field Conference, Guidebook, p. 89-98.

McLemore, V.T., North, R.M., and Leppert, Shawn, 1988, REE, niobium, and thorium districts and occurrences in New Mexico: New Mexico Bureau of Mines and Mineral Resources Open File Report 324, 27 p.

McLemore, V.T., and Quigley T., 1992, Epithermal gold-silver mineralization at the Alabama mine, Steeple Rock district, Grant County, New Mexico [abs.]: New Mexico Geology, v. 14, no. 3, p. 65.

McLeod, C.R., 1984, Placer gold, *in* Eckstrand, O.R., ed., Canadian mineral deposit types--a geological synopsis: Geological Survey of Canada Economic Geology Report 36, p. 23.

McMackin, C.E., 1977, Collecting "candy rock" and agate nodules in Deming, New Mexico area: Lapidary Journal, v. 31, no. 4.

McMackin, C.E., 1979, Memories of Ricolite Gulch: Lapidary Journal, v. 33, no. 5, p. 1184-1190.

McMahon, T.P., and Giordano, T.H., 1988, Structural and stratigraphic controls of deposition and microstratigraphy of fluorite-barite deposits in the southern Rio Grande rift, New Mexico [abs.]: New Mexico Geology, v. 10, no. 3, p. 68.

McOwen, L.K., 1993, The Brock Canyon volcanic complex, Grant County, New Mexico--Volcanic evolution, alteration, and mineralization: Tucson, University of Arizona Master's thesis, 167 p.

Measures, E.A., 1985, Carbonate facies of the Montoya Group--Description of a shoaling-upward ramp: West Texas Geological Society, Bulletin 25, no. 2, p. 4-8.

Meek, F.B., and Hayden, F.V., 1862, Descriptions of new Cretaceous fossils from Nebraska Territory: Academy of Natural Sciences of Philadelphia, Proceedings, p. 21–28.

Meeves, H.C., 1966, Reconnaissance of beryllium-bearing pegmatite deposits in southwestern states --Arizona, Colorado, New Mexico, South Dakota, Utah, and Wyoming: U.S. Bureau of Mines, Information Circular 8298, 34 p.

Meinert, L.D., 1987, Skarn zonation and fluid evolution in the Groundhog Mine, Central Mining District, New Mexico: Economic Geology Bulletin no. 3, p. 523-545.

Menzie, W.D., and Jones, G.M., 1986, Grade and tonnage model of W skarn deposits, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 55-57.

Menzie, W.D., and Singer, D.A., 1990, A course on mineral resource assessment: Proceedings at the International Symposium on Mineral Exploration--The Use of Artificial Intelligence, 1990, Tokyo and Tsukuba, Japan, p. 177-178.

Menzie, W.D., and Theodore, T.G., 1986, Grade and tonnage model of porphyry Mo, low-F, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 120-122.

Metcalf, A.L., 1967, Late Quaternary mollusks of the Rio Grande valley, Caballo Dam, New Mexico, to El Paso, Texas: El Paso, University of Texas, Texas Western Press, Science Series I, 62 p.

Metcalf, A.L., 1969, Quaternary surfaces, sediments, and mollusks, southern Mesilla Valley, New Mexico and Texas, *in* Cordoba, D.A., Wengerd, S.A., and Shomaker, J., eds., Guidebook of the Border Region, Chihuahua and the United States: New Mexico Geological Society, 20th Annual Field Conference, p. 158-164.

Metzger, O.H., 1938, Gold mining in New Mexico: U.S. Bureau of Mines, Information Circular, 6987, 71 p.

Meyer, Charles, 1981, Ore-forming processes in geologic history, *in* Skinner, B.J., ed., Economic Geology, Seventy-Fifth Anniversary Volume, 1905-1980: Economic Geology Publishing Company, p. 6-41.

Meyer, J.P., 1985, Fossils on Bear Mountain: Jewelry Making Gems and Minerals, v. 573, p. 14-15, 20-21.

Milbauer, J.A., 1983, The historical geography of the Silver City mining region of New Mexico: University of California, Los Angeles, unpublished Ph. D. dissertation, --- p.

Miley, F., 1981, An examination of red beryl: Gems and Gemology, v. 16, no. 12, p. 405-408.

Miller, B.M., 1983, ed., Petroleum potential of Wilderness lands in the western United States: U.S. Geological Survey Circular 902 A-P.

Millican, R.S., Jr., 1971, Geology and petrography of the Tertiary Riley-Cox Pluton, Doña Ana County, New Mexico: El Paso, University of Texas, unpublished Master's thesis, 87 p.

Millican, R.S., Jr., 1973, A note on the geology of Mount Riley and Mount Cox, *in* Hoffer, J.M., ed., The geology of south central Doña Ana County, New Mexico: El Paso Geological Society Guidebook no. 7, p. 47-49.

Million, D.T., 1986, Microfacies analysis and depositional environment comparison of two sections of Ordovician El Paso Formation, southern Franklin Mountains, west Texas, and northern Big Hatchet Mountains, southwest New Mexico [abs.]: New Mexico Geology, v. 8, no. 3, p. 68-69.

Minear, J.W., and Irving, A.J., 1979, Composite mantle xenoliths and melt movement: EOS, American Geophysical Union Transactions, v. 60, no. 18, p. 419.

Mitchell, J.R., 1991, Field trip--Collecting in a volcano: Rock and Gem, v. 21, no. 2, p. 86-88, 90-91.

Mizell, N.H., 1980, Inventory of geothermal leasing and drilling activity in New Mexico: New Mexico Geology, v. 2, no. 4, p. 53-54.

Molenaar, C.M., 1983, Major depositional cycles and regional correlations of Upper Cretaceous rocks, southern Colorado Plateau and adjacent areas, *in* Reynolds, M.W., and Dolly, E.D., eds., Mesozoic paleogeography of west-central United States: Society of Economic Paleontologists and Mineralogists, Rocky Mountain Section, p. 201-224.

Molenaar, C.M., 1989, North-south stratigraphic cross sections of upper Cretaceous rocks, northern San Juan Basin, southwestern Colorado; UlS. Geological Survey Miscellaneous Field Studies Map MF 2068, scale ca. 1:105,000.

Molenaar, C.M., Mack, G.H., Black, B.A., and Cobban, W.A., 1990, Stratigraphy and provenance of Upper Cretaceous rocks in south-central New Mexico [abs.]: AAPG Rocky Mountain Section Meeting; American Association of Petroleum Geologists Bulletin, v. 74, no. 8, p. 1338.

Molenaar, C.M., Mack, G.H., Black, B.A., and Cobban, W.A., 1990, Stratigraphy and provenance of Upper Cretaceous rocks in south-central New Mexico [abs.]: *in* Barker, C.E., Coury, A.B., eds., Abstracts of the U.S. Geological Survey central region; 1990 poster review: U.S. Geological Survey Open File Report 90-0656, p. 29.

Monger, H.C., Daugherty, L.A., Lindemann, W.C., and Liddell, C.M., 1991, Microbial precipitation of pedogenic calcite: Geology, v. 19, no. 10, p. 997-1000.

Moore, S.L., 1987, Geologic map of the Allie Canyon quadrangle, Grant County, New Mexico: U.S. Geological Survey Geologic Quadrangle Map GQ-1606, scale 1:24,000.

Moore, S.L., Foord, E.F., Meyer, G.A., and Smith, G.W., 1988, Geologic map of the northwestern part of the Mescalero Apache Indian Reservation, Otero County, New Mexico: U.S. Geological Survey Miscellaneous Investigations Series Map I–1895, scale 1:24,000.

Moore, S.L., Turner, R.L., Blank, H.R., Jr., and Korzeb, S.L., 1988, Mineral Resources of the Sierra de la Canas Wilderness Study Area, Socorro County, New Mexico: U.S. Geological Survey Bulletin 1734–D, p. D1– D11.

Morgan, J.W., and Baedecker, P.A., 1983, Elemental composition of sulfide particles from an ultramafic xenolith and the siderophile element content of the upper mantle: Proceedings of the Lunar and Planetary Science Conference, v. 14, pt. 2, p. 513-514.

Morgan, P., Callender, J.F., Harder, V., and Swanber, C.A., 1983, Hydrology and Geochemistry: Geothermal Resources of New Mexico Scientific Map Series, Scale 1:500,000.

Morgan, P., Seager, W.R., and Golombek, M.P., 1986, Cenozoic thermal, mechanical, and tectonic evolution of the Rio Grande rift: Journal of Geophysical Research, v. 91, p. 6263-6276.

Morgan, P., Swanberg, C.A., Dicey, T., Chaturvedi, L., and Jiracek, G.R., 1979, Geophysical evaluation of the Las Alturas Estates, New Mexico, geothermal prospect [abs.]: Society of Exploration Geophysics, Annual International Meeting, Abstracts, v. 49, p. 102.

Morgan, P., Swanberg, C.A., and Lohse, R.L., 1980, Borehole temperature studies of the Las Alturas geothermal anomaly, New Mexico, *in* Icerman, L., Starkey, A., and Trentman, N., eds., State-coupled Low Temperature Geothermal Resource Assessment Program, fiscal year 1979--Final technical report: p. 9.1-9.14.

Morris, H.T., 1986, Descriptive model of polymetallic replacement deposits, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 99-100.

Morris, R.W., 1974a, Geology and mineral deposits of the Northern Cook's Range, Grant County, New Mexico: El Paso, University of Texas, unpublished Master's thesis, 48 p.

Morris, R.W., 1974b, Geology and fluorspar deposits of the Northern Cook's Range, *in* Silver Anniversary Guidebook--Ghost Ranch, Central-northern New Mexico; Base metal and fluorspar districts of New Mexico--a symposium: New Mexico Geological Society, 25th Annual Field Conference, p. 381.

Morrison, R.B., 1965 [1966], Geologic map of the Duncan and Canador Peak quadrangles, Arizona and New Mexico: U.S. Geological Survey Miscellaneous Investigations Series Map I-0442, scale 1:48,000.

Mosier, D.L., 1986a, Descriptive model of replacement Mn, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 105.

Mosier, D.L., 1986b, Grade and tonnage model of replacement Mn, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 105-107.

Mosier, D.L., 1986c, Grade and tonnage model of Zn-Pb skarn deposits, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 90-93.

Mosier, D.L., 1986d, Descriptive model of epithermal Mn, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 165.
Mosier, D.L., 1986e, Grade and tonnage model of epithermal Mn, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 166-167.
Mosier, D.L., Berger, B.R., and Singer, D.A., 1986, Descriptive model of epithermal Sado epithermal veins, *in* Cox, D.P., and Singer, D.A., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 154.
Mosier, D.L., and Briskey, J.A., 1986, Grade and tonnage model of southeast Missouri Pb-Zn and Appalachian Zn, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 224-226.
Mosier, D.L., and Menzie, W.D., 1986a, Grade and tonnage model for Fe skarn deposits, *in* Cox, D.P., and Singer, D.A., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 94-97.
Mosier, D.L., and Menzie, W.D., 1986b, Grade and tonnage model epithermal quartz-alunite Au, *in* Cox, D.P., and Singer, D.A., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 159-161.
Mosier, D.L., Morris, H.T., and Singer, D.A., 1986, Grade and tonnage model of polymetallic replacement deposits, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 101-104.
Mosier, D.L., and Sato, Takeo, 1986, Grade and tonnage model of Sado epithermal veins, *in* Cox, D.P., and Singer, D.A., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 155-157.
Mosier, D.L., Sato, Takeo, Page, N.J, Singer, D.A., and Berger, B.R., 1986, Descriptive model of Creede epithermal veins, *in* Cox, D.P., and Singer, D.A., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 145.
Mosier, D.L., Sato, Takeo, and Singer, D.A., 1986, Grade and tonnage model of Creede epithermal veins, *in* Cox, D.P., and Singer, D.A., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 146-149.
Mosier, D.L., Singer, D.A., Bagby, W.C., and Menzie, W.D., 1992, Grade and tonnage model of sediment-hosted Au, *in* Bliss, J.D., ed., Developments in mineral deposit modeling: U.S. Geological Survey Bulletin 2004, p. 26-28.
Mosier, D.L., Singer, D.A., and Berger, B.R., 1986a, Descriptive model of epithermal Comstock epithermal veins, *in* Cox, D.P., and Singer, D.A., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 150.
Mosier, D.L., Singer, D.A., and Berger, B.R., 1986b, Grade and tonnage model of Comstock epithermal veins, *in* Cox, D.P., and Singer, D.A., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 151-153.
Mosier, D.L., Singer, D.A., and Cox, D.P., 1986, Grade and tonnage model of sediment-hosted Cu, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 206-208.
Muehlberger, W.R., 1965, Late Paleozoic movement along the Texas lineament: New York Academy of Sciences Transactions, series 2, v. 27, p. 385-392.
Muehlberger, W.R., 1980, Texas lineament revisited; *in* Dickerson, P.W., Hoffer, J.M., and Callender, J. F., eds., Trans-Pecos region (west Texas): New Mexico Geological Society, 31st Annual Field Conference, Guidebook, p. 113-121.
Muehlberger, W.R., and Wiley, M.A., 1970, The Texas lineament, *in* The geologic framework of the Chihuahua tectonic belt--Symposium in honor of Ronald K. DeFord, Midland, Texas, 1970: West Texas Geological Society, p. 8-15.

Mueller, J.E., and Twidale, C.R., 1988, Landform development of City of Rocks State Park and Giant of the Mimbres, *in* Mack, G.H., Lawton, T.F., and Lucas, S.G., eds., Cretaceous and Laramide tectonic evolution of southwestern New Mexico: New Mexico Geological Society, 39th annual field conference, Deming, N. Mex., p. 185-190.

Muffler, L.J.P., ed., 1979, Assessment of Geothermal Resources of the United States, 1978: U.S. Geological Survey Circular 790, 163 p.

Mullen, D.H., and Storms, W.R., 1948, Copper Flat zinc deposit, Central mining district, Grant County, New Mexico: U.S. Bureau of Mines Report of Investigations 4228, 8 p.

Mumpton, F.A., 1984, Zeolite exploration: The early days, *in* Olson, D.H., and Bisio, A., eds., Proceedings of the Sixth International Zeolite Conference: Guildford, U.K., Butterworths, p. 68-86.

Mumpton, F.A., ed., 1993, Mineralogy and geology of natural zeolites: Brockport, N.Y., International Committee on Natural Zeolites, 201 p.

Murphy, M.O., 1964, Moonstone of the Black Range, New Mexico: Lapidary Journal, v. 18, no. 1, p. 144-153.

Murray, C.R., and Theis, C.V., 1991, Ground-water conditions near Wilna, New Mexico, *in* Theis, C.V., ed., Short papers on water resources in New Mexico 1937-1957: U.S. Geological Survey Open-File Report 91-0081, p. 45-46.

Murray, John, and Renard, A.F., 1891, Report on deep-sea deposits, *in* Report of the scientific results of the voyage of H.M.S. Challenger during the years 1873-76: London, 520 p.

Myers, D.A., 1973, The upper Paleozoic Madera Group in the Manzano Mountains, New Mexico: U.S. Geological Survey Bulletin 1372–F, p. F1–F13.

Myers, R.G., 1983, Test wells T21, T22, and T25, White Sands Missile Range, Doña Ana County, New Mexico: U.S. Geological Survey Open-File Report 83-771, 37 p.

Myers, R.G., and Nickerson, E.L., 1988, Stream-aquifer relations in the Mesilla groundwater basin, Doña Ana County, New Mexico and El Paso County, Texas [abs.]: New Mexico Geology, v. 10, no. 3., p. 66-67.

Myers, R.G., and Orr, B.R., 1985, Geohydrology of the aquifer in the Santa Fe Group, northern West Mesa of the Mesilla Basin near Las Cruces, New Mexico: U.S. Geological Survey Water Resources Investigations 84-4190, 37 p.

Myers, R.G., and Pinckley, K.M., 1985a, Test wells T23, T29, and T30, White Sands Missile Range and Fort Bliss Military Reservation, Doña Ana County, New Mexico: U.S. Geological Survey Open-File Report 84-0805, 28 p.

Myers, R.G., and Pinckley, K.M., 1985b, Test wells T27 and T28B, White Sands Missile Range, Doña Ana County, New Mexico: U.S. Geological Survey Open-File Report 84-0809, 19 p.

Myers, R.G., and Pinckley, K.M., 1987, Test wells TW1, TW2, TW3, White Sands Missile Range, Otero County, New Mexico: U.S. Geological Survey Open-File Report 87-0047, 19 p.

Myers, R.G., and Sharp, S.C., 1989, Biannual water-resources review, White Sands Missile Range, New Mexico 1986 and 1987: U.S. Geological Survey Open-File Report 89-0049, 36 p.

Nash, J.T., 1994, Geochemical signatures of silver and gold deposits, Tonopah 1°x2° quadrangle, Nevada--description and applications to exploration: U.S. Geological Survey Bulletin 2077, 46 p.

Naumov, G. B., Motorina, Z. M., and Naumov, V. B., 1971, Conditions of formation of carbonates in veins of the lead-cobalt-nickel-silver-uranium type: Geochemistry International, v. 8, no. 4, p. 590-598.

Neal, J.T., 1976, Pleistocene Lake Trinity, a sulfate basin in the northern Jornada del Muerto, New Mexico [abs.]: Abstracts of the Fourth biennial meeting of the American Quaternary Association; American Quaternary Association National Conference Abstracts, v. 4, p. 155.

Neal, J.T., 1978, Satellite sensing of pluvial lake basins [abs.]: Geological Society of America Abstracts with Programs, v. 10, no. 7, p. 462.

Needham, C.E., and Bates, R.L., 1943, Permian type sections in central New Mexico: Geological Society of America Bulletin, v. 54, no. 11, p. 1653–1667.

Nelson, C.E., and Giles, D.L., 1985, Hydrothermal eruption mechanisms and hot spring gold deposits, *in* Sawkins, F.J., and Sillitoe, R.H., A special issue devoted to breccia-hosted ores: Economic Geology, v. 80, no. 6, p. 1633-1639.

Nelson, L.A., 1940, Paleozoic stratigraphy of Franklin Mountains, west Texas: American Association of Petroleum Geologists Bulletin, v. 24, no. 1, p. 157-172.

Nettleton, L.L., 1962, Gravity and magnetics for geologists and seismologists: American Association of Petroleum Geologists Bulletin, v. 46, no. 10, p. 3-7.

Newcomer, R.W., Jr., 1984, Geology, hydrothermal alteration and mineralization off the northern part of the Sugarloaf Peak Quartz Monzonite, Doña Ana County, New Mexico: Las Cruces, New Mexico State University, Master's thesis, 108 p.

Newcomer, R.W., Jr., and Giordano, T.H., 1986, Porphyry-type mineralization and alteration in the Organ mining district, south-central New Mexico: New Mexico Geology, v. 8, no. 4, p. 83-86.

Newcomer, R.W., Giordano, T.H., and Seager, W.R., 1983, Hydrothermal alteration and mineralization of the Sugarloaf Peak quartz monsonite, Doña Ana County, New Mexico [abs.]: Abstracts with Programs, Geological Society of America, Rocky Mountain and Cordilleran section joint meeting, v. 15, no. 5, p. 276.

New Mexico Energy Institute, 1980, Geothermal Resources of New Mexico: Map produced by NOAA for the Geothermal Division of the United States Department of Energy, scale 1:500,000.

New Mexico Geological Society, 1982, New Mexico Highway Geologic Map; Prepared in cooperation with the New Mexico Bureau Mines and Mineral Resources: Socorro, New Mexico, scale 1:1,000,000.

New Mexico State Highway Department, 1962, Aggregate resources and soils study--New Mexico Interstate 10: New Mexico State Highway Department, Materials and Testing Laboratory.

New Mexico State Mines Inspector, 1912-1982, Annual Reports: New Mexico Energy and Minerals Department, Albuquerque.

Nicholson, T.J., Wierenga, P.J., Gee, G.W., Jacobson, E.A., Polmann, D.J., McLaughlin, D.B., and Gelhar, L.W., 1989, Validation of stochastic flow and transport models for unsaturated soils; field study and preliminary results, *in* Buxton, B.E., ed., Proceedings of the conference on geostatistical, sensitivity, and uncertainty methods for ground-water flow and radionuclide transport modeling: Columbus, Ohio, Batelle Memorial Institute report CONF-870971, p. 275-296.

Nickerson, E.L., and Myers, R.G., 1992, Geohydrology of the Mesilla ground-water basin, Dona Ana County, New Mexico, and El Paso County, Texas, *in cooperation with* the New Mexico State Engineers Office: U.S. Geological Survey Water Resources Investigations 92-4156, 89 p.

Nielsen, R.L., 1968, Hypogene texture and mineral zoning in a copper-bearing granodiorite porphyry stock, Santa Rita, New Mexico: Economic Geology, no. 1, p. 37-50.

Nielsen, R.L., 1970, Mineralization and alteration in calcareous rocks near the Santa Rita stock, New Mexico, *in* Woodward, L.A., ed., Guidebook of the Tyrone-Big Hatchet Mountains-Florida Mountains region: New Mexico Geological Society Guidebook 21, p. 133-139.

Nightengale, A.L., and Mack, G.H., 1992, Stratigraphy, sedimentology, and provenance of sedimentary rocks of the Bell Top Formation (Oligocene), Doña Ana and Sierra Counties, New Mexico [abs.]: New Mexico Geological Society Proceedings Volume, 1992 Annual Spring Meeting, p. 13.

Nishi, J.M., Watts, K.C., and Alminas, H.V., 1981, Analyses of sieved stream sediments and the magnetic and nonmagnetic fractions of pan concentrates from the San Lorenzo 15-minute quadrangle, southwestern New Mexico: U.S. Geological Survey Open-File Report-81-0294, 123 p.

Nodeland, S., and Cornell, W.C., 1976, Microfossils of the Smeltertown Formation stratotype (Cretaceous, Albian), Mount Cristo Rey, New Mexico, *in* LeMone, D.V., and Lovejoy, E.M.P., Symposium on the Franklin Mountains: El Paso Geological Society Quinn Memorial Volume, p. 87-89.

Nolan, T.B., 1933, Epithermal precious metal deposits, *in* Ore deposits of the western states: New York, American Institute of Mining and Metallurgical Engineers, p. 623-640.

Norland, W.D., 1985, Thermal maturation of the Mesilla Valley Formation (Late Albian) on the north and east flanks of the Cerro de Cristo Rey pluton, Doña Ana County, New Mexico [abs.]: New Mexico Geology, v. 7, no. 3., p. 64.

Norland, W.D., and Cornell, W.C., 1986, Thermal maturation of Cretaceous palynomorphs by and Eocene andesite intrusion: Program and abstracts; American Association of Stratigraphic Palynologists, v. 19, p. 29.

Norman, D.I., Ting, Wupoa, Putnam, B.R., III, and Smith, R.W., 1985, Mineralization of the Hansonburg Mississippi Valley-type deposit, New Mexico--insight from composition of gases in fluid inclusions: Canadian Mineralogist, v. 23, part 3, p. 353-368.

North, R.M., and Eveleth, R.E., 1981, Report on the Battleship group of patented mining claims, Lordsburg mining district, Hidalgo County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Open-file Report 166, 27 p.

North, R.M., and McLemore, V.T., 1986, Silver and gold occurrences in New Mexico: New Mexico Bureau of Mines and Mineral Resources Resource Map 15, 32 p., scale 1:1,000,000.

North, R.M., and McLemore, V.T., 1988, A classification of the precious metal deposits of New Mexico, *in* Bulk minable precious metal deposits of the western United States: Geological Society of Nevada symposium proceedings, p. 625-659.

North, R.M., and Tuff, M.A., 1986, Fluid-inclusion and trace-element analyses of some barite-fluorite deposits in south-central New Mexico; in Clemons, R.E., King, W.E., and Mack, G.H., eds., Truth or Consequences Region: New Mexico Geological Society, Guidebook to the 37th field conference, p. 301-306.

Northrop, H.R., Rye, R.O., Landis, G.P., Lustwerk, R., Jones, M.B., and Daly, W.E., 1987, Sediment-hosted disseminated gold mineralization at Jerritt Canyon, Nevada--stable isotope geochemistry and a model of ore deposition, [abs.] *in* Dickinson, W.R., ed.: Geological Society of America Abstracts with Programs, v. 19, no. 7, p. 791.

Northrop, S.A., 1942, Minerals of New Mexico: Albuquerque, University of New Mexico Press, 665 p.

Nye, O.B., and LeMone, D.V., 1978, Multilaminar growth in *Reptomulticava texana*, a new species of cyclostome bryozoa: Journal of Paleontology, v. 52, no. 4, p. 830-845.

O'Brien, J.D., 1986, Preservation of primary magmatic features in subvolcanic pegmatites, aplites, and granite from Rabb Park, New Mexico, *in* Brown, G.E., Jr., and Ewing, R.C., ed., The mineralogy, petrology, and geochemistry of granitic pegmatites and related granitic rocks, R.H. Jahn memorial issue: American Mineralogist, 71, no. 3-4, p. 608-624.

O'Brien, K.M., and Stone, W.J., 1984, Role of geological and geophysical data in modeling a southwestern alluvial basin: Ground Water, v. 22, no. 6, p. 717-727.

O'Brien, K.M., and Stone, W.J., 1985, Role of geological and geophysical data in modeling an alluvial basin, southwest New Mexico, *in* Graves, B., Lehr, J.H., and Butcher, K., eds., Surface and borehole geophysical methods in ground water investigations; second national conference and exposition: National Water Well Association, Worthington, Ohio, p. 198-214.

O'Connor, G.A., and Khorsandi, F., 1987, Predicting chemical movement in soils: New Mexico State University Department of Agronomy and Horticulture, Las Cruces, Water Resources Institute Report M17, 17 p.

O'Donnell, J.E., Martinez, R., and Williams, J., 1975, Telluric current sounding near Kilbourne and Hunts Holes, New Mexico, *in* Seager, W.R., Clemons, R.E., and Callender, J.F., eds., Guidebook of the Las Cruces Country: New Mexico Geological Society, 26th Annual Field Conference, p. 279-280.

O'Neill, A.J., and Thiede, D.S., 1982, Silver City quadrangle, New Mexico and Arizona: Bendix Field Engineering Corporation, Grand Junction Operation PGJ/F-131(82), 87 p.

Olander, P.A.J., 1979, Authigenic mineral reactions in tuffaceous sedimentary rocks, Buckhorn, New Mexico: Laramie, University of Wyoming, unpublished Master's thesis, 60 p.

Ordonez, G., Baltosser, W.W., and Martin, K., 1955, Geologic structures surrounding the Santa Rita intrusive, New Mexico: Economic Geology, v. 50, p. 9-21.

Orr, B.R., and Myers, R.G., 1986, Water resources in basin-fill deposits in the Tularosa Basin, New Mexico: U.S. Geological Survey Water Resources Investigations 85-4219, 94 p.

Orr, B.R., and White, R.R., 1985, Selected hydrologic data from the northern part of the Hueco Bolson, New Mexico and Texas: U.S. Geological Survey Open-File Report 85-0696, 88 p.

Orris, G.J., 1991, Grade and tonnage model of oolitic ironstones, *in* Bliss, J.D., ed., Developments in mineral deposit modeling: U.S. Geological Survey Bulletin 2004, p. 41-43.

Orris, G.J., 1992a, Preliminary grade and tonnage model of lacustrine gypsum, *in* Orris, G.J., and Bliss, J.D., Industrial mineral deposit models--grade and tonnage models: U.S. Geological Survey Open-File Report 92-437, p. 60-62.

Orris, G.J., 1992b, Grade and tonnage model of barite veins, *in* Orris, G.J., and Bliss, J.D., eds., Industrial mineral deposit models--Grade and tonnage models: U.S. Geological Survey Open-File Report 92-437, p. 32-34.

Orris, G.J., 1992c, Preliminary grade and tonnage model of marine bedded gypsum, *in* Orris, G.J., and Bliss, J.D., eds., Industrial mineral deposit models--Grade and tonnage models: U.S. Geological Survey Open-File Report 92-437, p. 53-55.

Orris, G.J., 1992d, Preliminary grade and tonnage model of lacustrine gypsum; in Orris, G.J., and Bliss, J.D., Industrial mineral deposit models--Grade and tonnage models: U.S. Geological Survey Open-File Report 92-437, p. 60-62.

Orris, G.J., and Bliss, J.D., 1986, Grade and tonnage model of placer Au-PGE, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 261-264.

Orris, G.J., and Bliss, J.D., eds., 1991, Some industrial mineral deposit models--Descriptive deposit models: U.S. Geological Survey Open-File Report 91-11A, 73 p.

Orris, G.J., and Bliss, J.D., eds., 1992, Industrial minerals deposit models--grade and tonnage models: U.S. Geological Survey Open-File Report 92-437, 84 p.
Orris, G.J., Bliss, J.D., Hammarstrom, J.M., and Theodore, T.G., 1987, Description and grade and tonnages of gold-bearing skarns: U.S. Geological Survey Open-File Report 87-273, 50 p.
Ortiz, T.S., 1979, Megacrysts and mafic and ultramafic inclusions of the southern West Potrillo Basalt Field, Doña Ana County, New Mexico: El Paso, University of Texas, unpublished Master's thesis, 95 p.
Osburn, J.C., 1979, Evaluation of scoria deposits in New Mexico: New Mexico Bureau of Mines and Mineral Resources Annual Report, July 1, 1978, to June 30, 1979, p. 75-80.
Osburn, J.C., 1982, Scoria exploration and utilization in New Mexico, *in* Austin, G.S., compiler, Industrial rocks and minerals of the southwest: New Mexico Bureau of Mines and Mineral Resources Circular 182, p. 57-59.
Osburn, G.R., and Chapin, C.E., 1983, Nomenclature for Cenozoic rocks of the northeast Mogollon–Datil volcanic field, New Mexico: New Mexico Bureau of Mines and Mineral Resources Stratigraphic Chart 1, 7 p.
Osterberg, M., and Muller, P., 1994, Geology of the Cyprus Piños Altos deposit; in Trip 10 and 13; Tyrone, Pinos Altos, Chino, Continental, Central district, New Mexico: Bootprints along the Cordillera, Field Guide, 29 p.
Osterwald, F.W., 1961, Critical review of some tectonic problems in the Cordilleran foreland: American Association of Petroleum Geologists Bulletin, v. 45, p. 219-237.
Packard, F.A., 1955, The stratigraphy of the Upper Mississippian Paradise Formation of southeastern Arizona and southwestern New Mexico: Madison, University of Wisconsin, unpublished Master's thesis, unknown p.
Padovani, E.R., 1977, Granulite facies xenoliths from Kilbourne Hole maar, New Mexico, and their bearing on deep crustal evolution: University of Texas at Dallas, unpublished Ph. D. dissertation, 172 p.
Padovani, E.R., 1986, The ground truth from crustal xenoliths; a multifaceted approach, *in* Noller, J.S., Kirby, S.H., and Neilson-Pike, J.E., eds., Geophysics and petrology of the deep crust and upper mantle; a workshop sponsored by the U.S. Geological Survey and Stanford University: U.S. Geological Survey Circular 0956, p. 40-43.
Padovani, E.R., and Carter, J.L., 1973, Mineralogy and mineral chemistry of a suite of anhydrous, quartzo-feldspathic, garnet-bearing granulites from Kilbourne Hole maar, New Mexico [abs.]: Geological Society of America Abstracts with Programs, v. 5, no. 7, p. 761-762.
Padovani, E.R., and Carter, J.L., 1974, Blue sillimanite in garnet granulite xenoliths from Kilbourne Hole, New Mexico: Eos, American Geophysical Union Transactions, v. 55, no. 4, p. 482.
Padovani, E.R., and Carter, J.L., 1977, Non-equilibrium partial fusion due to decompression and thermal effects in crustal xenoliths, *in* Dick, H.J.B., ed., Magma genesis 1977--Proceedings of the American Geophysical Union Chapman conference on partial melting in the Earth's upper mantle: Oregon Department of Geology and Mineral Industries, Bulletin 96, p. 43-57.
Padovani, E.R., and Carter, J.L., 1978a, Aspects of the deep crustal evolution beneath south-central New Mexico, *in* Heacock, J.G., Keller, G.V., Oliver, J.E., and Simmons, G., eds., The Earth's crust; its nature and physical properties: American Geophysical Union, Geophysics Monographs, v. 20, p. 19-55.
Padovani, E.R., and Carter, J.L., 1978b, Deep crustal evolution beneath south-central New Mexico--Constraints on the geothermal gradient from xenolithic assemblages, *in* Olden,

K.H., and Chapin, C.E., eds., International symposium on the Rio Grande Rift; Program and abstracts: Los Alamos Scientific Laboratory report LA-C 7487, p. 66-67.
Padovani, E.R., and Hart, S.R., 1981, Geochemical constraints on the evolution of the lower crust beneath the Rio Grande Rift: Papers presented to the Conference on the processes of planetary rifting; Lunar and Planetary Institute Contribution 457, p. 149-152.
Padovani, E.R., and Reid, M.R., 1989, Field guide to Kilbourne Hole maar, Doña Ana County, New Mexico, *in* Chapin, C.E., and Zidek, Jiri, eds., Field excursions to volcanic terranes in the western United States, Vol. I--Southern Rocky Mountain region: New Mexico Bureau of Mines and Mineral Resources Memoir 46, p. 174-179.
Page, R.O., 1975, Malpais maar volcano, *in* Seager, W.R., Clemons, R.E., and Callender, J.F., eds., Guidebook of the Las Cruces Country: New Mexico Geological Society, 26th Annual Field Conference, p. 135-137.
Paige, S., 1908, The Hanover iron-ore deposits, New Mexico, in Iron and Manganese: U.S. Geological Survey, Bulletin 380-E, p. 199-214.
Paige, Sidney, 1911, The ore deposits near Pinos Altos, New Mexico, *in* Contributions to Economic Geology, 1910, Pt. 1, Metals and nonmetals except fuels: U.S. Geological Survey Bulletin 470, p. 109-124.
Paige, Sidney, 1912, The geologic and structural relationship at Santa Rita (Chino), New Mexico: Economic Geology, v. 7, p. 547–559.
Paige, Sidney, 1916, Description of the Silver City quadrangle, New Mexico: U.S. Geological Survey Geologic Atlas of the United States, Folio 199, 19 p.
Paige, Sidney, 1922, Copper deposits of the Tyrone district, New Mexico: U.S. Geological Survey Professional Paper 122.
Pallister, J.S., du Bray, E.A., and Hall, D.B., 1993, Geology of Chiricahua National Monument--A review for the non-specialist: U.S. Geological Survey Open-File Report 93-0617, 17 p.
Pallister, J.S., du Bray, E.A., in press, Guide to the volcanic geology of Chiricahua National Monument and vicinity, Cochise County, Arizona: U.S. Geological Survey Miscellaneous Investigation Series Map I—2541 , 1:24,000.
Pankratz, L.W., Ackermann, H.D., and Jachens, R.C., 1978, Results and interpretation of geophysical studies near the Picacho fault, south-central Arizona: U.S. Geological Survey Open-File Report 78-933, 17 p.
Papke, K.G., 1987, Gypsum deposits in Nevada: Nevada Bureau of Mines and Geology Bulletin 103, 26 p.
Parry, W.T., Ballantyne, J.M., and Jacobs, D.C., 1984, Geochemistry of hydrothermal sericite from Roosevelt Hot Springs and the Tintic and Santa Rita porphyry copper systems: Economic Geology and the Bulletin of the Society of Economic Geologists, v. 79, no. 1, p. 72-86.
Patterson, C.M., 1947, Alteration in the Santa Rita copper deposits, Santa Rita, New Mexico: New York, Columbia University, unpublished Ph. D. dissertation, unknown p.
Patterson, J.L., 1965, Magnitude and frequency of floods in the United States Part 8, western Gulf of Mexico basins: U.S. Geological Survey Water-Supply Paper 1682, p. 419-422.
Patterson, S.H., 1977, Diatomite, *in* Mineral and water resources of New Mexico: U.S. Congress, 89th, 1st session, Senate Committee on Interior and Insular Affairs: New Mexico Bureau of Mines and Mineral Resources Bulletin 87, p. 322-324.
Patterson, S.H., and Holmes, R.W., 1965, Clays, *in* Mineral and water resources of New Mexico: U.S. Congress, 89th, 1st session, Senate Committee on Interior and Insular Affairs: New Mexico Bureau of Mines and Mineral Resources Bulletin 87, p. 312-322.

Pearson, B., 1988, A three-hundred-mile fault zone--The trans-Pecos rift?, *in* Reid, S.T., Bass, R.O., and Welch, P., eds., Guadalupe Mountains revisited--Texas and New Mexico: West Texas Geological Society Publication 88-84, 202 p.

Perry, F.V., Baldridge, W.S., and DePaolo, D.J., 1987, Role of asthenosphere and lithosphere in the genesis of Late Cenozoic basaltic rocks from the Rio Grande Rift and adjacent regions of the southwestern United States: Journal of Geophysical Research, v. 92, no. B9, p. 9193-9213.

Peterson, D.M., 1986, Enhanced conceptualization of Mesilla Bolson geohydrology through modelling studies [abs.]: New Mexico Geology, v. 8, no. 3, p. 70.

Peterson, J.A., Cox, D.P., and Gray, Floyd, 1987, Mineral resource assessment of the Ajo and Lukeville 1°x2° quadrangles, Arizona: U.S. Geological Survey Miscellaneous Field Studies Map MF-1834-B, 39 p.

Peterson, N.V., and Mason, R.S., 1983, Pumice, pumicite, and volcanic cinders, *in* Le Fond, S.J., ed., Industrial minerals and rocks: Society of Mining Engineers (AIME), New York, New York, p. 1079-1084.

Peterson, S.L., 1976, Geology of the Apache No. 2 mining district, Hidalgo County, New Mexico: Albuquerque, University of New Mexico, unpublished Master's thesis, 86 p.

Phillips, J.D., Duval, J.S., and Ambroziak, R.A., 1993, National geophysical data grids: gamma-ray, gravity, magnetic, and topographic data for the conterminous United States: U.S. Geological Survey Digital Data Series DDS-9, 1 CD-ROM.

Pickens, C.A., 1983, An Early Cretaceous rudist biostrome sequence in East Potrillo Mountains, Doña Ana County, New Mexico [abs.]: New Mexico Geology, v. 5, no. 3, p. 64.

Pike, J.E.N., 1980, Composite spinel lherzolite/spinel-olivine pyroxenite/metagabbroid xenolith from Kilbourne Hole, New Mexico, *in* Irving, A.J., and Dungan, M.A., eds., The Jackson Volume: American Journal of Science, v. 280-A, part: p. v-vi.

Pitts, P.D., 1949, Temperature relations at Oswaldo Mine, Santa Rita, New Mexico: University of Toronto, Canada, unpublished Master's thesis, unknown p.

Plouff, Donald, 1977, Preliminary documentation for a Fortran program to compute gravity terrain corrections based on topography digitized on a geographic grid: U.S. Geological Survey Open-File Report 77-535, 45 p.

Plouff, Donald, and Pakiser, L.C., 1972, Gravity study of the San Juan Mountains, Colorado: U.S. Geological Survey Professional Paper 800-B, p. B183-B190.

Pond, W.G., and Mumpton, F.A., eds., 1984, Zeo-Agriculture--Use of natural zeolites in agriculture and aquaculture: Boulder, Colo., Westview Press, 296 p.

Pond, W.G., and Yen, J.T., 1984, Physiological effects of clinoptilolite and synthetic zeolite A in animals, *in* Pond, W.G., and Mumpton, F.A., eds., Zeo-Agriculture--Use of natural zeolites in agriculture and aquaculture: Boulder, Colo., Westview Press, p. 127-142.

Poole, F.G., Stewart, J.H., Palmer, A.R., Sandberg, C.A., Madrid, R.J., Ross, R.J., Jr., Hintze, L.F., Miller, M.M., and Wrucke, C.T., 1992, Latest Precambrian to latest Devonian time—Development of a continental margin, *in* Burchfiel, B.C., Lipman, P.W., and Zoback, M.L., The Cordilleran Orogen—Conterminous U.S.: Geological Society of America, Geology of North America, v. G3, p. 9–56.

Powell, D.L., 1983, Stratigraphic nomenclature of East Potrillo Mountains, Doña Ana County, New Mexico [abs.]: New Mexico Geology, v. 5, no. 3, p. 64.

Powers, R.S., 1976, Geology of the Summit Mountains and vicinity, Grant County, New Mexico and Greenlee County, Arizona: Houston, Tex., University of Houston, unpublished Master's thesis, 107 p.

Pradhan, B.M., and Singh, Y.I., 1960, Geology of the area between Virden and Red Rock, Hidalgo and Grant Counties, New Mexico, unpublished M.S. thesis, Albuquerque, University of New Mexico, 74 p.

Pratt, W.P., 1967, Geology of the Hurley West quadrangle, Grant County, New Mexico: U.S. Geological Survey Bulletin 1241-E, p. E1-E91.

Pratt, W.P., and Jones, W.R., 1961, Montoya Dolomite and Fusselman Dolomite in Silver City region, New Mexico: American Association of Petroleum Geologists, Bulletin, v. 45, p. 484-500.

Pray, L.C., 1953, Upper Ordovician and Silurian stratigraphy of the Sacramento Mountains, Otero County, New Mexico: American Association of Petroleum Geologists Bulletin, v. 37, no. 8, p. 1894–1918.

Pray, L.C., 1958, Stratigraphic section, Montoya Group and Fusselman Formation, Franklin Mountains, Texas: West Texas Geological Society Guidebook, p. 30-42.

Presley, G.C., 1994, Pumice and pumicite: Mining Engineering, v. 46, p. 542–543.

Putnam, B.R., III, Norman, D.I., and Smith, R.W., 1983, Mississippi Valley-type lead-fluorite-barite deposits of the Hansonburg mining district: New Mexico Geological Society, Guidebook, 34th Field Conference, p. 253-259.

Pyron, A.J., 1980, Geology and geochemistry of the El Paso tin deposits, Franklin Mountains, El Paso County, Texas: El Paso, University of Texas, unpublished Master's thesis, unknown p.

Pyron, A.J., and Gray, J.H., 1985, Don't ignore the Orogrande--Its potential is promising: World Oil, v. 200, no. 6, p. 59-60, 62, 64, 66-67.

Quaide, W.L., 1953, Geology of the central Peloncillo Mountains, Hidalgo County, New Mexico: Berkeley, University of California, unpublished Master's thesis, 87 p.

Quillin, B., and Coombs, J., 1978, Microearthquake survey of the Radium Springs KGRA, south-central New Mexico, *in* Combs, J., ed., Geothermal energy--A novelty becomes a resource: Transactions, Geothermal Resources Council, v. 2, sec. 2 (Hilo, Hawaii), p. 547-550.

Raines, G.L., 1984, Preliminary map showing limonitic areas in the Silver City 1°x2° quadrangle, Arizona and New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map MF-1183-Q, scale 1:250,000.

Raines, G.L., Erdman, J.A., McCarthy, J.H., and Reimer, G.M., 1985, Remotely sensed limonite anomaly on Lordsburg Mesa, New Mexico--Possible implications for uranium deposits: Economic Geology and the Bulletin of the Society of Economic Geologists, v. 80, no. 3, p. 575-590.

Ralogg, J., 1981, Bigfoot or big feet?: Science News (Washington), v. 120, no. 11, p. 172-173.

Ramberg, I.B., Cook, F.A., and Smithson, S.B., 1978, Structure of the Rio Grande Rift in southern New Mexico and West Texas based on gravity interpretation: Geological Society of America Bulletin, v. 89, no. 1, p. 107-123.

Ramirez, R.O., McMillan, N.J., Dickin, A.P., 1994, Geochemistry and petrology of the Eocene Rubio Peak volcanic suite, southern New Mexico [abs.]: Geological Society of America, Rocky Mountain Section; Abstracts with Programs, v. 26, no. 6, p. 60.

Ransome, F.L., 1904, Description of the Bisbee quadrangle, Arizona: U.S. Geological Survey Geologic Atlas Folio, 17 p.

Ransome, F.L., 1904, The geology and ore deposits of the Bisbee quadrangle, Arizona: U.S. Geological Survey Professional Paper 21, 168 p.

Ransome, F.L., 1915, The Tertiary orogeny of the North American Cordillera and its problems, *in* Problems of American geology: New Haven, Conn., Yale University Press, p. 287-376.

Ratkevich, R., 1979a, A search for the giant birds of New Mexico's past: Lapidary Journal, v. 33, no. 9, p. 1946-1948.
Ratkevich, R.P., 1979b, Fossil lizard tracks of the Mesilla Valley, New Mexico: Lapidary Journal, v. 33, no. 8, p. 1750-1751.
Ratkevich, Ronald, 1980, Permian lizard tracks of the Mesilla Valley, New Mexico: Rocks and Minerals, v. 55, no. 6, p. 236-239.
Ratkevich, R.P., 1982, Fossil mammals of New Mexico's Paleocene: Lapidary Journal, v. 36, no. 3, p. 586-590.
Ratkevich, R., and La Fon, N., 1978, Field guide to New Mexico fossils: Alamogordo, N. Mex., Dinograph Southwest, 78 p.
Ratté, J.C., 1978, Supplemental road log No. 4; Gila mining district, *in* Chapin, C.E., Elston, W.E., and James, H.L., Field guide to selected cauldrons and mining districts of the Datil-Mogollon volcanic field, New Mexico: New Mexico Geological Society Special Publication 7, p. 86-87.
Ratté, J.C., 1981, Geologic map of the Mogollon quadrangle, Catron County, New Mexico: U.S. Geological Survey Geologic Quadrangle Map GQ–1557, scale 1:24,000.
Ratté, J.C., 1982 [1983], Reserve graben, southwestern New Mexico and eastern Arizona, *in* Geological Survey Research 1982: U.S. Geological Survey Professional Paper, p. 61.
Ratté, J.C., 1989, Geologic map of the Bull Basin quadrangle, Catron County, New Mexico: U.S. Geological Survey Geologic Quadrangle Map GQ–1651, scale 1:24,000.
Ratté, J.C., Bove, D.J., and McIntosh, W.C., 1994, Geologic map of the Milligan Mountain quadrangle, Catron County, New Mexico: U.S. Geological Survey Geologic Quadrangle Map GQ–1736, scale 1:24,000.
Ratté, J.C., and Briggs, J.P., 1984, Hells Hole Roadless Area, Arizona and New Mexico, *in* Marsh, S.P., Kropschot, S.J., and Dickinson, R.G., eds., Wilderness mineral potential; assessment of mineral resource potential in U.S. Forest Service lands studied 1964-1984: U.S. Geological Survey Professional Paper 1300, p. 73-75.
Ratté, J.C., and Brooks, W.E., 1983, Geologic map of the Mule Creek quadrangle, Grant County, New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map MF-1666.
Ratté, J.C., and Brooks, W.E., 1989, Geologic map of the Wilson Mountain quadrangle, Catron and Grant Counties, New Mexico: U.S. Geological Survey Geologic Quadrangle Map GQ-1611.
Ratté, J.C., Cather, S.M., Chapin, C.E., Duffield, W.A., Elston, W.E., and McIntosh, W.C., 1989, Excursion 6A--Eocene-Miocene Mogollon-Datil volcanic field, New Mexico, *in* Chapin, C.E., and Zidek, Jiri, eds., Field excursions to volcanic terranes in the western United States, Volume I--Southern Rocky Mountain region: New Mexico Bureau of Mines and Mineral Resources Memoir 46, p. 43-119.
Ratté, J.C., and Gaskill, D.L., 1973, Relative ages of the Gila Cliff Dwellings and Bursum calderas, Mogollon Mountains, New Mexico [abs.]: Geological Society of America Abstracts with Programs, v. 5, no. 6, p. 505.
Ratté, J.C., and Gaskill, D.L., 1975 [1976], Reconnaissance geologic map of the Gila Wilderness study area, southwestern New Mexico: U.S. Geological Survey Miscellaneous Investigations Series Map I-0886, 2 sheets, scale 1:62,500.
Ratté, J.C., Gaskill, D.L., Eaton, G.P., Peterson, D.L., Stotelmeyer, R.B., and Meeves, H.C., 1972, Mineral resources of the Gila Primitive Area and Gila Wilderness, Catron and Grant Counties, New Mexico: U.S. Geological Survey Open–File Report 72–306, 428 p. .
Ratté, J.C., Gaskill, D.L., Eaton, G.P., Peterson, D.L., Stotelmeyer, R.B., and Meeves, H.C., 1979, Mineral resources of the Gila Primitive Area and Gila Wilderness, New Mexico: U.S. Geological Survey Bulletin 1451, 229 p.

Ratté, J.C., Hassemer, J.R., Martin, R.A., and Briggs, J.P., 1982a, Mineral resource potential of the Hells Hole further planning area (RARE II), Greenlee County, Arizona, and Grant County, New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map MF-1344-E, 7 p.

Ratté, J.C., Hassemer, J.R., Martin, R.A., and Lane, Michael, 198b, Mineral resource potential of the Lower San Francisco Wilderness Study Area and contiguous Roadless Area, Greenlee County, Arizona, and Catron and Grant Counties, New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map MF-1463-C, scale 1:62,500.

Ratté, J.C., and Hedlund, D.C., 1981, Geologic map of the Hells Hole further planning area (RARE II), Greenlee County, Arizona, and Grant County, New Mexico: U.S. Geological Survey Map MF-1344-A, scale 1:62,000.

Ratté, J.C., and Lane, M.E., 1984, Lower San Francisco Wilderness Study Area and contiguous roadless areas, Arizona and New Mexico, *in* Marsh, S.P., Kropschot, S.J., and Dickinson, R.G., eds., Wilderness mineral potential; assessment of mineral-resource potential in U.S. Forest Service lands studied 1964-1984: U.S. Geological Survey Professional Paper 1300, p. 79-82.

Ratté, J.C., Marvin, R.F., and Naeser, C.W., 1984, Calderas and ash flow tuffs of the Mogollon Mountains, southwestern New Mexico: Journal of Geophysical Research, v. 89, no. 10, p. 8713-8732.

Ratté, J.C., and Stotelmeyer, R.B., 1984, Gila Wilderness, New Mexico, *in* Marsh, S.P., Kropschot, S.J., and Dickinson, R.G., eds., Wilderness mineral potential; assessment of mineral resource potential in U.S. Forest Service lands studied 1964-1984: U.S. Geological Survey Professional Paper 1300, p. 811-813.

Raup, O.B., 1991, Descriptive model of bedded gypsum; deposit subtype--marine evaporite gypsum, *in* Oriss, G.J., and Bliss, J.D., eds., Some industrial mineral deposit models--Descriptive deposit models: U.S. Geological Survey Open-File Report 91-11A, 34-35 p.

Raup, R., 1952, Relationship between zinc ores and gossan at Hanover, New Mexico: Ann Arbor, University of Michigan, unpublished Master's thesis, unknown p.

Reed, B.L., and Cox, D.P., 1986, Descriptive model of Sn skarn deposits, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 58.

Reed, B.L., Duffield, Wendell, Ludington, S.D., Maxwell, C.H., and Richter, D.H., 1986, Descriptive model of rhyolite-hosted Sn, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 168.

Reed, M.J., ed., 1983, Assessment of low-temperature geothermal resources of the United States -1982: U.S. Geological Circular 892, 73 p.

Reeder, H.O., 1957, Ground water in Animas Valley, Hidalgo County, New Mexico, *with a section on* geology by Z.E. Spiegel: Reports Section, Technical Division, New Mexico State Engineers Office, Technical Report 11, v. 4, 101 p.

Reeves, C.C., 1965, Pluvial Lake Palomas, northwestern Chihuahua, Mexico, and Pleistocene geologic history of south-central New Mexico, *in* Fitzsimmons, J.P., and Lochman-Balk, Christina, eds., Guidebook of southwestern New Mexico II: New Mexico Geological Society, 16th Annual Field Conference, p. 199-203.

Reeves, C.C., Jr., and DeHon, R.A., 1965, Geology of Potrillo Maar, New Mexico and northern Chihuahua, Mexico: American Journal of Science, v. 63, p. 401-409.

Rehrig, W.A., and Heidrick, T.L., 1976, Regional tectonic stress during the Laramide and later Tertiary intrusive periods, Basin and Range province, Arizona: Arizona Geological Society Digest, v. 10, p. 205-228.

Reiche, Parry, 1938, Recent fault scarps, Organ Mountain district, New Mexico: American Journal of Science, v. 36, p. 440-444.

Reiche, Parry, 1940, The origin of Kilbourne Hole, New Mexico: American Journal of Science, v. 238, no. 3, p. 212-225.
Reid, J.B., Jr., 1977, A comparison of partial melting processes beneath Hawaii and the southern Rio Grande Rift, *in* Dick, H.J.B., ed., Magma genesis 1977--Proceedings of the American Geophysical Union Chapman conference on partial melting in the Earth's upper mantle: Oregon Department of Geology and Mineral Industries Bulletin 96, p. 307.
Reid, J.B., Jr., Eggleton, M., and Oppenheimer, D.A., 1979, The creation and evolution of primitive sea floor basalt magmas: Eos, American Geophysical Union, Transactions, v. 60, no. 46, p. 970-971.
Reid, M.R., 1989, Compositional dependence of Pb isotopic signatures in the lower crust exhibited by xenoliths from Kilbourne Hole, New Mexico [abs.], *in* Continental Magmatism Abstracts, International Association of Volcanology and Chemistry of the Earth's Interior; General Assembly, Santa Fe, New Mexico, USA, June 25-July 1, 1989: New Mexico Bureau of Mines and Mineral Resources Bulletin 131, p. 222.
Reid, M.R., 1990, Ion-probe investigation of rare-earth element distributions and partial melting of metasedimentary granulites, *in* Vielzeuf, D., and Vidal, P., eds., Granulites and crustal evolution: NATO Advanced Study Institutes Series C (Mathematical and Physical Sciences) no. 311, p. 507-522.
Reid, M.R., Hart, S.R., Padovani, E.R., and Wandless, G.A., 1989, Contribution of metapelitic sediments to the composition, heat production, and seismic velocity of the lower crust of southern New Mexico, USA: Earth and Planetary Science Letters, v. 95, nos. 3-4, p. 367-381.
Reinke, R.E., 1978, Surface wave propagation in the Tularosa and Jornada del Muerto basins, south-central New Mexico: Southern Methodist University, unpublished Ph. D. dissertation, 161 p.
Reiter, D.F., 1980, Geology of the Alamo-Hueco and Dog Mountains, Hidalgo County, New Mexico: Albuquerque, University of New Mexico, unpublished Master's thesis, 100 p.
Reiter, M., and Barroll, M.W., 1990, High heat flow in the Jornada del Muerto; a region of crustal thinning in the Rio Grande Rift without upper crustal extension, *in* Luccitta, I., and Morgan, P., eds., Heat and detachment in continental extension: Tectonophysics, v. 174, nos. 1-2, p. 183-195.
Reiter, M., Edwards, C.L., Hartman, H., and Weidman, C., 1975, Terrestrial heat-flow along the Rio Grande rift, New Mexico and southern Colorado: Geological Society of America Bulletin, v. 86, p. 811-818.
Reiter, Marshall, Eggleston, R.E., Broadwell, B.R., and Minier, Jeffrie, 1986, Estimates of the terrestrial heat flow from deep petroleum tests along the Rio Grande rift in central and southern New Mexico: Journal of Geophysical Research, v. 91, no. B6, p. 6225-6245.
Renault, Jacques, 1970, Major-element variations in the Potrillo, Carrizozo, and McCartys basalt fields, New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 113, 22 p.
Renault, Jacques, 1979, Silica crystallite geothermometer; initial calibration [abs.]: Geological Society of America Abstracts with Programs, v. 11, no. 7, p. 502.
Repetski, J.E., 1988, Ordovician conodonts from the Bliss Sandstone in its type area, West Texas, *in* Wolberg, D.L., ed., Contributions to Paleozoic paleontology and stratigraphy in honor of Rousseau H. Flower: New Mexico Bureau of Mines and Mineral Resources Memoir 44, p. 123–127.
Repetski, J.E., and Drewes, H.B., 1979, Ordovician Montoya Group extended westward in southeastern Arizona: U.S. Geological Survey Professional Paper 1150, p. 83

Reynolds, R.L., 1977, Paleomagnetism of welded tuffs of the Yellowstone group: Journal of Geophysical Research, v. 82, p. 3677-3693.
Reynolds, S.J., 1988, Geologic map of Arizona: Arizona Geological Survey, map 26, scale 1:1,000,000.
Reynolds, T.J., and Beane, R.E., 1985, Evolution of hydrothermal fluid characteristics at the Santa Rita, New Mexico, porphyry copper deposit: Economic Geology, v. 5, p. 1328-1347.
Rhodes, R.C., 1970, Volcanic rocks associated with the western part of the Mogollon Plateau volcano-tectonic complex, southwestern New Mexico: Albuquerque, University of New Mexico, unpublished Ph. D. dissertation, 145 p.
Rhodes, R.C., 1976a, Petrologic framework of the Mogollon Plateau volcanic ring complex, New Mexico--surface expression of a major batholith, *in* Cenozoic volcanism in southwestern New Mexico: New Mexico Geological Society, Special Publication 5, p. 103-112.
Rhodes, R.C., 1976b, Volcanic geology of the Mogollon Range and adjacent areas, Catron and Grant Counties, New Mexico, *in* Elston, W.E., and Northrup, S.A., eds., Cenozoic volcanism in southwestern New Mexico: New Mexico Geological Society Special Publication no. 5, p. 42-50.
Rhodes, R.C., and Smith, E.I., 1976, Stratigraphy and structure of the northwestern part of the Mogollon Plateau volcanic province, Catron County, New Mexico; Cenozoic volcanism in southwestern New Mexico: New Mexico Geological Society Special Publication 5, p. 57–62.
Richard, E., and Courtright, J.H., 1960, Some Cretaceous–Tertiary relationships in southeastern Arizona and New Mexico: Arizona geological Society Digest, v. 3, p. 1–7.
Richardson, G.B., 1904, Report of a reconnaissance in Trans-Pecos Texas, north of the Texas and Pacific Railway: Texas University Mineral Survey, Bulletin 9, 119 p.
Richardson, G.B., 1906, Tin in the northern Franklin Mountains, Texas: U.S. Geological Survey Bulletin 285-C, p. 146-149.
Richardson, G.B., 1908, Paleozoic formations in trans-Pecos Texas: American Journal of Science, 4th series, v. 25, p. 474-484.
Richter, D.H., Houser, B.B., Watts, K.C., Klein, D.P., Sharp, W.N., Drewes, H.D., Hedlund, D.C., Raines, G.L., and Hassemer, J.R., 1987, The Conterminous United States Mineral Assessment Program--Background information to accompany folio of geologic and mineral resource maps of the Silver City 1°x2° quadrangle, New Mexico and Arizona: U.S. Geological Survey Circular-0975, 22 p.
Richter, D.H., and Lawrence, V.A., 1983, Mineral deposit map of the Silver City 1°x 2° quadrangle, New Mexico and Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map I-1310-B, 70 p., scale 1:250,000.
Richter, D.H., Lawrence, V.A., Barton, Harlan, Hanna, William, Duval, J.S., and Ryan, G.S., 1988, Mineral resources of the Gila Lower Box Wilderness Study Area, Grant and Hidalgo Counties, New Mexico: U.S. Geological Survey Bulletin 1735-A, p. A1-A13.
Richter, D.H., Lawrence, V.A., Drewes, Harald, Young, T.H., Enders, M.S., Damon, P.E., and Thorman, C.H., 1990, Geologic map of the San Simon quadrangle and parts of the Summit Hills and Mondel Quadrangles, Cochise, Graham, and Greenlee Counties, Arizona, and Hidalgo County, New Mexico: U.S. Geological Survey Miscellaneous Investigations Series Map I-1951, scale 1:48,000.
Richter, D.H., and Sharp, W.N., 1984a, Mineral resource potential of the Silver City 1°x2° quadrangle, New Mexico-Arizona; Map A, Geologic map: U.S. Geological Survey Open-File Report 84-0629-A.

Richter, D.H., and Sharp, W.N., 1984b, Mineral resource potential of the Silver City 1°x2° quadrangle, New Mexico-Arizona; Map B, Copper resource potential: U.S. Geological Survey Open-File Report 84-0629-B.
Richter, D.H., and Sharp, W.N., 1984c, Mineral resource potential of the Silver City 1°x2° quadrangle, New Mexico-Arizona; Map C, Molybdenum resource potential: U.S. Geological Survey Open-File Report 84-0629-C.
Richter, D.H., and Sharp, W.N., 1984d, Mineral resource potential of the Silver City 1°x2° quadrangle, New Mexico-Arizona; Map D, Zinc and lead resource potential: U.S. Geological Survey Open-File Report 84-0629-D.
Richter, D.H., and Sharp, W.N., 1984e, Mineral resource potential of the Silver City 1°x2° quadrangle, New Mexico-Arizona; Map E, Gold and silver resource potential: U.S. Geological Survey Open-File Report 84-0629-E.
Richter, D.H., and Sharp, W.N., 1984f, Mineral resource potential of the Silver City 1°x2° quadrangle, New Mexico-Arizona; Map F, Tin resource potential: U.S. Geological Survey Open-File Report 84-0629-F.
Richter, D.H., and Sharp, W.N., 1984g, Mineral resource potential of the Silver City 1°x2° quadrangle, New Mexico-Arizona; Map G, Iron, nickel, and cobalt resource potential: U.S. Geological Survey Open-File Report 84-0629-G.
Richter, D.H., and Sharp, W.N., 1984h, Mineral resource potential of the Silver City 1°x2° quadrangle New Mexico-Arizona; Map H, Manganese and manganese-iron resource potential: U.S. Geological Survey Open-File Report 84-0629-H.
Richter, D.H., and Sharp, W.N., 1984i, Mineral resource potential of the Silver City 1°x2° quadrangle, New Mexico-Arizona; Map I, Tungsten and beryllium resource potential: U.S. Geological Survey Open-File Report 84-0629-I.
Richter, D.H., and Sharp, W.N., 1984j, Mineral resource potential of the Silver City 1°x2° quadrangle, New Mexico-Arizona; Map J, Uranium resource potential: U.S. Geological Survey Open-File Report 84-0629-J.
Richter, D.H., and Sharp, W.N., 1984k, Mineral resource potential of the Silver City 1°x2° quadrangle, New Mexico-Arizona; Map K, Fluorite resource potential: U.S. Geological Survey Open-File Report 84-0629-K.
Richter, D.H., and Sharp, W.N., 1984l, Mineral resource potential of the Silver City 1°x2° quadrangle, New Mexico-Arizona; Map L, Zeolites and diatomite resource potential: U.S. Geological Survey Open-File Report 84-0629-L.
Richter, D.H., and Sharp, W.N., 1984m, Mineral resource potential of the Silver City 1°x2° quadrangle, New Mexico-Arizona; Map M, Area in which resource potentials are designated; area in which no resource potential is designated: U.S. Geological Survey Open-File Report 84-0629-M.
Richter, D.H., Sharp, W.N., Watts, K.C., Raines, G.L., Houser, B.B., and Klein, D.P., 1983, Mineral resource assessment of the Silver City 1°x2° quadrangle, New Mexico: U.S. Geological Survey Open-File Report 83-0924, 77 p.
Richter, D.H., Sharp, W.N., Watts, K.C., Raines, G.L., Houser, B.B., and Klein, D.P., 1986, Known and possible mineral deposit types in the Silver City 1°x2° quadrangle, New Mexico and Arizona--Descriptions, recognition criteria, and resource evaluations: U.S. Geological Survey Miscellaneous Field Investigations Map I-1310-F, and pamphlet, 24 p.
Riecker, R.E., ed., 1979, Rio Grande rift: Tectonics and magmatism: Washington, D.C., American Geophysical Union, 438 p.
Riley, Robert, 1983, Preliminary evaluation of facies model analysis of Fort Hancock and Camp Rice Formations--west Texas and south-central New Mexico [abs.]: New Mexico Geology, v. 5, no. 3, p. 64.

Riotte, L., 1981, 250-acre rock hound wonderland: Lost Treasure, v. 6, no. 5, p. 44-47.
Risser, D.W., 1988, Simulated water-level and water-quality changes in the bolson-fill aquifer, Post Headquarters area, White Sands Missile Range, New Mexico: U.S. Geological Survey Water Resources Investigations 87-4152, 71 p.
Roark, R.C., LeMone, D.V., and Von Finger, Kevin, 1983, Stratigraphy of Pennsylvanian System, north Franklin Mountains, Doña Ana County, New Mexico [abs.]: New Mexico Geology, v. 5, no. 3, p. 64.
Robbins, E.I., 1981, Accumulation of fossil fuels and minerals in active and ancient rifts; Papers presented to the Conference on the processes of planetary rifting: Lunar and Planetary Institute Contribution 457, p. 188-191.
Roberts, R.G., and Sheahan, P.A., eds., 1988, Ore deposit models: Geological Society of Canada, Geoscience Canada, Reprint Series 3, 194 p.
Robinson, R.W., 1984, Geology, structure, and mineralization in the Steeple Rock mining district [abs.], *in* Eggleston, T.L., ed., Epithermal deposits in New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 199, p. 54.
Rockhold, M.L., and Wurstner, S.K., 1990, Simulations of unsaturated flow and transport in heterogeneous soil [abs.]: Geological Society of America Abstracts with Programs, v. 22, no. 7, p. 54.
Roden, M.F., Irving, A.J., and Murthy, V.R., 1988, Isotopic and trace element composition of the upper mantle beneath a young continental rift; results from Kilbourne Hole, New Mexico: Geochimica et Cosmochimica Acta, v. 52, no. 2, p. 461-473.
Roedder, Edwin, Heyl, A.V., and Creel, J.P., 1968, Environment of ore deposition at the Mex-Tex deposits, Hansonburg district, New Mexico, from studies of fluid inclusions: Economic Geology, v. 63, no. 4, p. 336-348.
Roepke, T.J., 1983, Preliminary analysis--Pennsylvanian stratigraphy of Robledo Mountains, Doña Ana County, New Mexico [abs.]: New Mexico Geology, v. 5, no. 3, p. 65.
Roeske, R.H., Garrett, J.M., and Eychaner, J.H., 1989, Floods of October 1983 in southeastern Arizona: U.S. Geological Survey, *in cooperation with* the U.S. Army Corps of Engineers, U.S. Bureau of Reclamation, and Arizona Department of Water Resources, Water Resources Investigations 85-4225-C, 77 p.
Root, D.H., Menzie, W.D., and Scott, W.A., 1992, Computer Monte Carlo simulation in quantitative resource estimation: Non-renewable resources, v. 1, no. 2, p. 125-138.
Root, D.H., and Scott, W.A., 1988, User manual for mineral simulation program: U.S. Geological Survey Open-File Report 88-15, 64 p.
Rose, A.W., and Baltosser, W.W., 1966, The porphyry copper deposit at Santa Rita, New Mexico, *in* Titley, S.R., and Hicks, C.L., eds., Geology of porphyry copper deposits, southwestern North America: Tucson, University of Arizona Press, p. 205-220.
Rosenzweig, A., 1960, Optical and twin orientation of spurrite: Geological Society of America Bulletin, v. 71, no. 12, pt. 2, p. 2073-2074.
Ross, C.A., 1978, Pennsylvanian and Early Permian depositional framework, southeastern Arizona, *in* Callender, J.F., Wilt, J.C., Clemons, R.E., and James, H.L., eds., Land of Cochise, southeastern Arizona: New Mexico Geological Society, 29th Annual Field Conference, Guidebook, p. 193-200. (also: American Association of Petroleum Geologists Bulletin, v. 57, no. 5, p. 887-912)
Ross, C.A., 1979, Late Paleozoic collision of North and South America: Geology, v. 7, no. 1, p. 41-44.
Ross, C.A., and Ross, J.R.P., 1986, Paleozoic paleotectonics and sedimentation in Arizona and New Mexico, *in* Peterson, J.A., eds., Paleotectonics and sedimentation in the Rocky

Mountain Region, United States: American Association of Petroleum Geologists, Memoir 41, p. 653-668.
Rossin, E.L., 1924, Petrography of a contact metamorphic deposit near Hanover, New Mexico: New York, Columbia University, unpublished Master's thesis, unknown p.
Roswell Geological Society, 1958, Guidebook of the Hatchet Mountains and the Cooks Range--Florida Mountain areas, Grant, Hidalgo and Luna Counties, southwestern New Mexico; 11th field conference, May 14, 15 and 16, 1958, 140 p.
Rothrock, H.E., 1970, Fluorspar, *in* Woodward, L.A., ed., Guidebook of the Tyrone-Big Hatchet Mountains-Florida Mountains Region: New Mexico Geological Society, 21st Annual Field Conference, p. 123-125.
Rothrock, H.E., Johnson, C.H., and Hahn, A.D., 1946, Fluorspar resources of New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 21, 239 p.
Ruff, R.K., 1993, Gas analysis of fluid inclusions--Application toward precious metal exploration, Steeple rock mining district, Grant County, New Mexico: Socorro, New Mexico Institute of Mining and Technology, unpublished Master's thesis, 89 p.
Ruhe, R.V., 1960, Age of the Rio Grande Valley in southern New Mexico: Geological Society of America Bulletin, v. 71, no. 12, pt. 2, p. 1962-1963.
Ruhe, R.V., 1961, Landscapes and soils in the southern New Mexico desert--Organ Peak and Las Cruces quadrangles and adjacent areas, Dona Ana County, *in* Guidebook of the Albuquerque Country: New Mexico Geological Society, 12th Annual Field Conference, p. 194-195.
Ruhe, R.V., 1962, Age of the Rio Grande Valley in southern New Mexico: Journal of Geology, v. 70, no. 2, p. 151-167.
Ruhe, R.V., 1963, Landscape morphology and fluvial deposits in southern New Mexico: Annals Association of American Geographers, v. 53, no. 4, p. 619.
Ruhe, R.V., 1964, Landscape morphology and alluvial deposits in southern New Mexico: Annals Association of American Geographers, v. 54, no. 1, p. 147-159.
Ruhe, R.V., 1967, Geomorphic surfaces and surficial deposits in southern New Mexico: New Mexico Bureau of Mines and Mineral Resources Memoir 18, 66 p.
Ruhe, R.V., and Daniels, R.B., 1965, Landscape erosion--Geologic and historic: Soil and Water Conservation Journal, v. 20, no. 2, p. 52-57.
Rupert, M.G., 1986, Structure and stratigraphy of the Klondike Hills, southwestern New Mexico: Las Cruces, New Mexico State University, unpublished Master's thesis, 138 p.
Rupert, M.G., 1988, Klondike Hills, southwestern New Mexico--Evidence for Laramide strike-slip deformation, *in* Mack, G.H., Lawton, T.F., and Lucas, S.G., eds., Cretaceous and Laramide tectonic evolution of southwestern New Mexico: New Mexico Geological Society, 39th annual field conference, Deming, N. Mex., p. 16-25.
Rupert, M.G., and Clemons, R.E., 1990, Stratigraphy and structure of the Klondike Hills, southwestern New Mexico: New Mexico Geology, v. 12, no. 2, p. 23-30.
Russell, P.L., 1947a, Steeple Rock zinc-lead district, Grant County, New Mexico: U.S. Bureau of Mines RI 4073, 13 p.
Russell, P.L., 1947b, Exploration of the Fluorite Ridge fluorspar district, Luna County, New Mexico: U.S. Bureau of Mines Report of Investigations, 7 p.
Russell, P.L., 1947c, Gila fluorspar district, Grant County, New Mexico: U.S. Bureau of Mines, Report of Investigations 4020, 5 p.
Ryan, G.S., 1985, Mineral investigations of part of the Gila Lower Box Wilderness Study Area (NM-030-023), Grant and Hidalgo Counties, New Mexico: U.S. Bureau of Mines Open-file Report MLA 74-85, 12 p.

Ryder, R.T., 1983a, Petroleum potential of wilderness lands, New Mexico: U.S. Geological Survey Miscellaneous Investigations Series Map I-1543, scale 1:1,000,000.
Ryder, R.T., 1983b, Petroleum potential of Wilderness lands, New Mexico, *in* Miller, B.M., ed., Petroleum potential of Wilderness lands in the Western United States: U.S. Geological Survey Circular 902-A-P, p. I-1 to I-33.
Rye, R.O., Bethke, P.M., and Wasserman, M.D., 1992, The stable isotope geochemistry of acid-sulfate alteration: Economic Geology, v. 87, p. 225-264.
Rytuba, J.J., 1981, Relation of calderas to ore deposits in the western United States, *in* Relations of tectonics to ore deposits in the southern Cordillera: Arizona Geological Society Digest, v. 14, p. 227-236.
Sabins, F.F., Jr., 1957, Stratigraphic relations in Chiricahua and Dos Cabezas Mountains, Arizona: American Association of Petroleum Geologists Bulletin, v. 41, no. 3, p. 466–510.
Sabins, F.F., Jr., and Ross, C.A., 1965, Stratigraphy and fusulinids of Naco Group in Chiricahua and Dos Cabezas Mountains, Arizona, *in* Guidebook of Southwestern New Mexico II: New Mexico Geological Society Sixteenth Field Conference, p. 148–157.
Sandidge, Michael, 1982, Aptian-Albian ammonoids of the Oyster Limestone member of the U-Bar Formation, Big Hatchet Mountains, New Mexico [abs.]: New Mexico Geology, v. 4, no. 1, p. 13.
Sandidge, Michael, 1983, Preliminary report on Carbonate Hill Limestone (Aptian) of central Peloncillo Mountains, Hidalgo County, New Mexico [abs.]: New Mexico Geology, v. 5, no. 3, p. 65.
Sanford, A.R., Budding, A.J., Hoffman, J.P., Alptekin, O.S., Rush, C.A., and Topposada, R.T., 1972, Seismicity of the Rio Grande rift in New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 120, 19 p.
Sangster, D.F., 1972, Precambrian volcanogenic massive sulfide deposits in Canada--A review: Geological Survey of Canada, Paper no. 72-22, 44 p.
Sangster, D.F., 1973, Silver-lead-zinc veins, *in* Geology of Canadian lead and zinc deposits, Report of activities, pt. A, April to October: Geological Survey of Canada, Paper no. 73-1, p. 129-130.
Sangster, D.F., 1984, Felsic intrusion-associated silver-lead-zinc veins, *in* Eckstrand, O.R., ed., Canadian mineral deposit types--a geological synopsis: Geological Survey of Canada Economic Geology Report 36, p. 66.
Sangster, D.F., 1986, Classification, distribution and grade-tonnage summaries of Canadian lead-zinc deposits: Geological Survey of Canada Economic Geology Report 37, p. 17.
Sangster, D.F., and Scott, S.D., 1976, Precambrian, strata–bound, massive Cu–Zn–Pb sulfide ores of North America, *in* Wolf, K.H., Handbook of strata–bound and stratiform ore deposits; II. Regional studies and specific deposits; v. 6, Cu, Zn, Pb, and Ag deposits: New York, Elsevier, p. 129–222.
Sargent, K.A., 1989, Potential host media for radioactive waste, *in* Bedinger, M.S., Sargent, K.A., and Langer, W.H., eds., Studies of geology and hydrology in the Basin and Range Province, southwestern United States, for isolation of high-level radioactive waste; characterization of the Rio Grande region, New Mexico and Texas: U.S. Geological Survey Professional Paper 1370-C, p. C20-C22.
Sargent, K.A., Hawley, J.W., Henry, C.C., Stone, W.J., and Kottlowski, F.E., 1989, Quaternary tectonism, *in* Bedinger, M.S., Sargent, K.A., and Langer, W.H., eds., Studies of geology and hydrology in the Basin and Range Province, southwestern United States, for isolation of high-level radioactive waste--Characterization of the Rio Grande region, New Mexico and Texas: U.S. Geological Survey Professional Paper 1370-C, p. C23-C26.

Sawyer, D.A., and Pallister, J.S., 1989, Geologic framework of the southern Basin and Range, *in* Chapin, C.E., and Zidek, Jiri, eds., Field excursions to volcanic terranes in the western United States, Volume I--Southern Rocky Mountain region: New Mexico Bureau of Mines and Mineral Resources Memoir 46, p. 121-126.

Sayala, D., 1972, A geochemical study of elemental distribution in ores and limestones from New Jersey zinc mines, Hanover, New Mexico: Albuquerque, University of New Mexico, unpublished Master's thesis, unknown p.

Sayre, A.N., and Livingston, P., 1945, Ground-water resources of the El Paso area, Texas: U.S. Geological Survey Water-Supply Paper 919, 190 p.

Scharkan, E.F., 1992, Economic geology and geochemistry of selected perlite occurrences in southwest New Mexico: Socorro, New Mexico Institute of Mining and Technology, unpublished Master's thesis, 190 p.

Schenk, C.J., and Fryberger, S.G., 1986, Early diagenesis in eolian dune and interdune sands at White Sands, New Mexico [abs.]: Sediments Down-under; Abstracts, 12th International Sedimentological Congress, Canberra, Australia, p. 268.

Schilling, J.H., 1965, Molybdenum resources of New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 76, 76 p.

Schmidt, R.R., 1987, Zeolites: Their market potential and occurrence in New Mexico: New Mexico Energy and Mineral Department Report of Investigation 1, 68 p.

Schmitt, H.A., 1935, The Central mining district, New Mexico: Transactions of the American Institute of Mining and Metallurgical Engineers, v. 115, Mining Geology, p. 186-209

Schmitt, H.A., 1939, The Pewabic mine: Geological Society of America Bulletin, v. 50, p. 777-818.

Schmitt, H. A., 1942, Certain ore deposits in the Southwest, Central mining district, New Mexico, in Newhouse, W.H., ed., Ore deposits as related to structural features: Princeton, N.J., Princeton University Press, p. 73-79.

Schneider, R.V., and Keller, G.R., 1994, Crustal structure of the western margin of the Rio Grande rift and Mogollon-Datil volcanic field, southwestern New Mexico and southeastern Arizona, *in* Keller, G.R., and Cather, S.M., eds., Basins of the Rio Grande Rift -- Structure, stratigraphy, and tectonic setting: Boulder, Colorado, Geological Society of America Special Paper 291. p. 207-226.

Schultze, L.E., and Zamzow, M.J., 1993, Acid mine drainage cleanup using natural zeolites [abs.], *in* Industrial Minerals in Environmental Applications Symposium: Cordilleran Section of the Geological Association of Canada, Program of Abstracts and Papers, p. 46-52.

Schwartz, G.M., 1959, Hydrothermal alteration: Economic Geology, v. 54, p. 161-183.

Schwennesen, A.T., 1918, Ground water in the Animas, Playas, Hachita, and San Luis basins, Arizona and New Mexico: U.S. Geological Survey Water-Supply Paper 422, 152 p.

Schwennesen, A.T., and Meinzer, O.E., 1917, Ground water in San Simon Valley, Arizona and New Mexico: U.S. Geological Survey Water-Supply Paper 425, p. 1-35.

Scott, D.C., 1986, Mineral resources of a part of the Big Hatchet Mountains Wilderness Study Area (NM-030-035), Hidalgo County, New Mexico: U.S. Bureau of Mines Mineral Land Assessment Open File Report 16-86, 31 p.

Scott, D.C., 1987a, Mineral investigation of additional parts of the Big Hatchet Mountains Wilderness Study Area (NM-030-035), Hidalgo County, New Mexico: U.S. Bureau of Mines Mineral Land Assessment Open File Report MLA 61-87, 9 p.

Scott, D.C., 1987b, Mineral investigation of the Cowboy Spring Wilderness Study Area (NM-030-007), Hidalgo County, New Mexico: U.S. Bureau of Mines Open File Report MLA 68-87, 10 p.

Seager, W.R., 1973a, Geologic map and sections of Bishop Cap-Organ Mountains Area, New Mexico: New Mexico Bureau of Mines and Mineral Resources Geologic Map 29, scale 1:24,000.
Seager, W.R., 1973b, Resurgent volcano-tectonic depression of Oligocene age, south-central New Mexico: Geological Society of America Bulletin, v. 84, p. 3611-3626.
Seager, W.R., 1975a, Cenozoic tectonic evolution of the Las Cruces area, New Mexico, *in* Seager, W.R., Clemons, R.E., and Callender, J.F., eds., Guidebook of the Las Cruces Country: New Mexico Geological Society, 26th Annual Field Conference, p. 241-250.
Seager, W.R., 1975b, Geology of south half San Diego Mountain quadrangle, New Mexico: New Mexico Bureau of Mines and Mineral Resources Geologic Map 35, scale 1:24,000.
Seager, W.R., 1977, Rio Grande Rift in southern New Mexico [abs.]: Geological Society of America Abstracts with Programs, v. 9, no. 1, p. 72.
Seager, W.R., 1980, Quaternary-age fault system in the Tularosa and Hueco Basins, southern New Mexico and west Texas, *in* Dickerson, P.W., Hoffer, J.M., and Callender, J.F., eds., Trans Pecos region (west Texas): New Mexico Geological Society, 31st Annual Field Conference, Guidebook, p. 131-136.
Seager, W.R., 1981, Geology of Organ Mountains and southern San Andres Mountains, New Mexico: New Mexico Bureau of Mines and Mineral Resources Memoir 36, 97 p.
Seager, W.R., 1983, Laramide wrench faults, basement-cored uplifts, and complimentary (sic) basins in southern New Mexico: New Mexico Geology, v. 5, no. 4, p. 69-76.
Seager, W.R., 1987, Caldera-like collapse at Kilbourne Hole maar, New Mexico: New Mexico Geology, v. 9, p. 69-73.
Seager, W.R., 1988, Uplift, erosion, and burial of Laramide fault blocks, Salado Mountains, Sierra County, New Mexico: New Mexico Geology, v. 10, no. 3, p. 49-53.
Seager, W.R., 1989, Geology beneath and around the West Potrillo basalts, Doña Ana and Luna Counties, New Mexico: New Mexico Geology, v. 11, no. 3, p. 53-59.
Seager, W.R., 1995, Geology of southwest quarter of Las Cruces and northwest El Paso 1°x2° sheets, New Mexico: New Mexico Bureau of Mines and Mineral Resources Geologic Map 60, scale 1:125,000.
Seager, W.R., 1994, Reconnaissance geologic map of Kaylor Mountain 15' quadrangle, Doña Ana and Sierra Counties, New Mexico: New Mexico Bureau of Mines and Mineral Resources Open File Report OF-401, 1 sheet, scale 1:48,000.
Seager, W.R., and Brown, L.F., 1978, The Organ Caldera, *in* Chapin, C.E., Elston, W.E., and James, H.L., eds., Field guide to selected cauldrons and mining districts of the Datil-Mogollon volcanic field, New Mexico: New Mexico Geological Society Special Publication 7, p. 139-149.
Seager, W.R., and Clemons, R.E., 1975, Middle to late Tertiary geology of Cedar Hills-Selden Hills area, New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 133, 24 p.
Seager, W.R., and Clemons, R.E., 1988, Geology of Hermanas quadrangle, Luna County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Geologic Map 63, scale 1:24,000.
Seager, W.R., and Clemons, R.E., 1989, Geology of the Las Cruces area, New Mexico, *in* Drewes, H., and Dyer, R., eds., Sedimentation and tectonics of western North America, volume 2--Tectonics of the eastern part of the Cordilleran orogenic belt, Chihuahua; New Mexico and Arizona: Washington, D.C., American Geophysical Union, p. 11-15.
Seager, W.R., Clemons, R.E., and Callender, J.F., eds., 1975, Guidebook of the Las Cruces Country: New Mexico Geological Society, 26th Annual Field Conference, 376 p.

Seager, W.R., Clemons, R.E., and Hawley, J.W., 1975, Geology of Sierra Alta quadrangle, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 102, 56 p.
Seager, W.R., Clemons, R.E., Hawley, J.W., and Kelley, R.E., 1982, Geology of northwest part of Las Cruces 1°x2° sheet, New Mexico: New Mexico Bureau of Mines and Mineral Resources Geologic Map 53, sheet 1, scale 1:125,000.
Seager, W.R., 1980, Quaternary fault system in the Tularosa and Hueco basins, southern New Mexico and West Texas; *in* Dickerson, P.W., Hoffer, J.M., and Callender, J. F., eds., Trans-Pecos region (west Texas): New Mexico Geological Society, 31st Annual Field Conference, Guidebook, p. 131-135.
Seager, W.R., and Hawley, J.W., 1973, Geology of Rincon quadrangle, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 101, 42 p., map scale 1:24,000.
Seager, W.R., Hawley, J.W., and Clemons, R.E., 1971, Geology of San Diego Mountain area, Doña Ana County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 97, 38 p.
Seager, W.R., Hawley, J.W., Kottlowski, F.E., and Kelley, S.A., 1987, Geology of east half of Las Cruces and northeast El Paso 1°x2° sheets, New Mexico: New Mexico Bureau of Mines and Mineral Resources Geologic Map 57, scale 1:125,000.
Seager, W.R., Kottlowski, F.E., and Hawley, J.W., 1976, Geology of Doña Ana Mountains, New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 147, 36 p.
Seager, W.R., and Mack, G.H., 1986a, Summary of geology of East Potrillo Mountains area: El Paso Geological Society, Guidebook, p. 158-159.
Seager, W.R., and Mack, G.H., 1986b, Laramide paleotectonics of southern New Mexico, *in* Peterson, J.A., ed., Paleotectonics and Sedimentation in the Rocky Mountain Region, United States: American Association of Petroleum Geologists Memoir 41, 669-685.
Seager, W.R., and Mack, G.H., 1990, Eagle Nest-Granite Hill area, Luna County, New Mexico--A new look at some old rocks: New Mexico Geology, v. 12, p. 1-7, 19.
Seager, W.R., and Mack, G.H., 1991, Geology of Garfield quadrangle, Sierra and Doña Ana Counties, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 128, 24 p., scale 1:24,000.
Seager, W.R., and Mack, G.H., 1994, Geology of East Potrillo Mountains and vicinity, Doña Ana County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 113, 27 p.
Seager, W.R., Mack, G.H., Raimonde, M.S., and Ryan, R.G., 1986, Laramide basement-cored uplift and basins in south-central New Mexico, *in* Clemons, R.E., King, W., and Mack, G.H., eds., Truth or Consequences region: New Mexico Geological Society Guidebook, 37th annual field conference, p. 123-130.
Seager, W.R., and McCurry, M., 1988a, The cogenetic Organ cauldron and batholith, south central New Mexico--Evolution of a large-volume ash flow cauldron and its source magma chamber, *in* Tilling, R.E., ed., Special section on How Volcanoes Work, Pt. 2: Hawaii symposium; Journal of Geophysical Research, v. 93, no. 5, p. 4421-4433.
Seager, W.R., and McCurry, M., 1988b, The cogenetic Organ cauldron batholith, south-central New Mexico--Evolution of a large volume ash-flow cauldron and its source chamber, *in* Tilling, R.I., ed., Part 2; Special Section on How Volcanoes Work: Journal of Geophysical Research, May 10, 1988, v. 93, no. 5, p. 4421-4433.
Seager, W.R., and Morgan, Paul, 1979, Rio Grande rift in southern New Mexico, west Texas, and northern Chihuahua, *in* Reicker, R.E., ed., Rio Grande rift; tectonics and magmatism: American Geophysical Union, Washington, D.C., p. 87-106.
Seager, W.R., Shafiqullah, M., and Clemons, R.E., 1981, Active fault analysis and radiometric dating of young basalts in southern New Mexico, *in* Icerman, L., Starkey, A., and

Trentman, N., eds., State-coupled low temperature geothermal resource assessment program, fiscal year 1981, Final technical report: New Mexico Energy Institute at New Mexico State University, p. 6-1 - 6-7.

Seager, W.R., Shafiqullah, M., Hawley, J.W., and Marvin, R., 1984, New K-Ar dates from basalt and the evolution of the southern Rio Grande rift: Geological Society of America Bulletin, v. 95, no. 1, p. 87-99.

Seewald, K.O., 1975, Petroleum prospects of the Orogrande Basin, *in* Exploration from the Mountains to the basin: Transactions, Joint meeting, Southwest Section, American Association of Petroleum Geologists and Permian Basin Section, Society of Economic Paleontologists and Mineralogists, El Paso, Texas, p. 39.

Segerstrom, Kenneth, Stotelmeyer, R.B., and Williams, F.E., 1979, Mineral resources of the White Mountain Wilderness and adjacent areas, Lincoln County, New Mexico: U.S. Geological Survey Bulletin 1453, 135 p.

Setra, A., 1976, Stratigraphy and microfacies analyses of the Mississippian Las Cruces Formation (Osage– Meramec), Vinton Canyon, El Paso County, Texas, *in* LeMone, D.V., and Lovejoy, E.M.P., Symposium on the Franklin Mountains: El Paso Geological Society, p. 45–49.

Shannon, W.M., and Barnes, C.G., 1991, Summary of the geochemistry and petrology of Proterozoic granitic rocks, Franklin Mountains, west Texas, *in* Julian, Betsy, and Zidek, Jiri, Field guide to geologic excursions in New Mexico and adjacent areas of Texas and Colorado: New Mexico Bureau of Mines and Mineral Resources Bulletin 137, p. 7-12.

Shantz, Robert, 1979, Mining, milling, and smelting operations in southwest New Mexico: New Mexico Geology, v. 1, no. 2, p. 24-26.

Sharp, R.R., Morris, W.A., and Aamodt, P.L., 1978, Uranium hydrogeochemical and stream sediment reconnaissance data release for the New Mexico portions of the Douglas, Silver City, Clifton, and Saint Johns NTMS quadrangles, New Mexico/Arizona: Los Alamos Scientific Laboratories Report 7180, 123 p. (also U.S. Department of Energy, Report GJBX-69(78)

Sharp, W.N., 1991, Petrochemistry of igneous rocks, Silver City 1°x2° quadrangle, New Mexico and Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map I-1310-H, 7 p.

Shawe, D.R., ed., 1976, Geology and resources of fluorine in the United States: U.S. Geological Survey Professional Paper 933, 99 p.

Sheahan, P.W., and Cherry, M.E., eds., 1993, Ore deposit models; volume II: Geological Society of Canada, Geoscience Canada, Reprint Series 6, 154 p.

Shenk, J.D., 1991, Lacustrine diatomite, *in* Orris, G.J., and Bliss, J.D., eds., Some industrial mineral deposit models--Descriptive deposit models: U.S. Geological Survey Open-File Report 91-11A, p. 23-25.

Sheppard, R.A., 1971, Zeolites in sedimentary deposits of the United States--a review, *in* Gould, R.F., ed., Molecular sieve zeolites--I: American Chemical Society Advances in Chemistry Series 101, p. 279-310.

Sheppard, R.A., 1973, Zeolites in sedimentary rocks, *in* Brobst, D.A., and Pratt, W.P., eds., United States mineral resources: U.S. Geological Survey Professional Paper 820, p. 689-695.

Sheppard, R.A., 1991, Descriptive model of sedimentary zeolites, deposit subtype--Zeolites in tuffs of saline, alkaline-lake deposits, *in* Orris, G.J., and Bliss, J.D., eds., Some industrial mineral deposit models--Descriptive deposit models: U.S. Geological Survey Open-File Report 91-11A, p. 16-18.

Sheppard, R.A., and Gude, A.J., 3d, 1982, Mineralogy, chemistry, gas adsorption, and NH_{4+}-exchange capacity for selected zeolitic tuffs from the western United States: U.S. Geological Survey Open-File Report 82-969, 16 p.

Sheppard, R.A. and Gude, A.J., 3d, 1987, Mineralogy and genesis of the Buckhorn zeolite deposit, Grant County, New Mexico, *in* Mumpton, F.A., ed., Zeo-Trip '87--An excursion to selected zeolite and clay deposits in southwestern New Mexico and eastern Arizona: Brockport, N.Y., International Committee on Natural Zeolites, p. 13-26.

Sheppard, R.A., and Mumpton, F.A., 1984, Sedimentary fluorite in a lacustrine zeolitic tuff of the Gila Conglomerate near Buckhorn, Grant County, New Mexico: Journal of Sedimentary Petrology, v. 54, p. 853-860.

Shimmin, J.T., 1927, The Hurley mill, water supply and power plant: New Mexico Chapter, American Mining Congress, Technical papers delivered on July 25-26, 1927, 1-4 p.

Shoemaker, E.M., 1957, Primary structures of maar rims and their bearing on the origin of Kilbourne Hole and Zuni Salt Lake, New Mexico [abs.]: Geological Society of America Bulletin, v, 68, no. 12, p. 1864.

Shumard, B.F., 1860, Observations on the Cretaceous strata of Texas, *in* Texas Almanac for 1861: Galveston, Richardson and Co., v. 4, p. 203–205.

Siemers, W.T., 1982, New Mexico limestones--Geology, uses, and economic potential of high-calcium limestone, *in* Austin, G.S., compiler, Industrial rocks and minerals of the southwest: New Mexico Bureau of Mines and Mineral Resources Circular 182, p. 39-42.

Siemers, W.T., and Austin, G.S., 1979a, Mines, processing plants, and power plants in New Mexico: New Mexico Bureau of Mines and Mineral Resources Mineral Resource Map RM-9, scale 1:1,000,000.

Siemers, W.T., and Austin, G.S., 1979b, Industrial rocks and minerals of New Mexico: New Mexico Bureau of Mines and Mineral Resources Annual Report, 1977-78, p. 43-61.

Silberman, M.L., McLemore, V.T., and Osterman, Chris, 1994, Mineral deposits of New Mexico--A summary of large districts and deposits: U.S. Geological Survey Administrative Report, January, 1994, 68 p.

Sillitoe, R.H, and Bonham, H.F., Jr., 1984, Volcanic landforms and ore deposits: Economic Geology, v. 79, no. 6, p. 1286-1298.

Sillitoe, R.H., Halls, C., and Grant, J.N., 1975, Porphyry tin deposits in Bolivia: Economic Geology, v. 70, no. 5, p. 913-927.

Simons, E.L., and Alexander, H.L., 1964, Age of the Shasta ground sloth from Aden Crater, New Mexico: American Antiquity, v. 29, p. 390-391.

Simpson, E.L., 1983, The geometry and structure of interdune deposits at White Sands National Monument, New Mexico: Lincoln, University of Nebraska, unpublished Master's thesis, unknown p.

Simpson, R.D., and LeMone, D., 1982, Permian brachiopods from the Alacran Mountain Formation, Franklin Mountains, Texas and New Mexico [abs.]: New Mexico Geology, v. 4, no. 1, p. 13.

Simpson, R.D., 1984, Permian Brachiopoda from far West Texas and southwestern New Mexico: University of Texas at El Paso, unpublished Ph. D. dissertation, 429 p.

Simpson, R.W., and Jachens, R.C., 1989, Gravity methods in regional Studies, *in* Pakiser, L.C., and Mooney, W.D., eds., Geophysical framework of the continental United States: Boulder, Colorado, Geological society of America Memoir 172, p.35-44.

Sinclair, W.D., and Kirkham, R.V., 1984, Vein--Stockwork tin, *in* Eckstrand, O.R., Canadian mineral deposit types--a geological synopsis: Geological Survey of Canada Economic Geology Report 36, p. 53-54.

Singer, D.A., 1986a, Grade and tonnage model of Besshi massive sulfide, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 136-138.
Singer, D.A., 1986b, Descriptive model of Cyprus massive sulfide, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 130.
Singer, D.A., 1986c, Descriptive model of Kuroko massive sulfide, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 189-190.
Singer, D.A., 1986d, Grade and tonnage model of porphyry Cu, skarn-related deposits, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 82-85.
Singer, D.A., 1993, Basic concepts in three-part quantitative assessments of undiscovered mineral resources: Nonrenewable Resources, v. 2, no. 2, p. 69-81.
Singer, D.A., Cox, D.P., and Mosier, D.L., 1986, Grade and tonnage model of porphyry Cu-Mo, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 116-119.
Singer, D.A., and Mosier, D.L., 1986a, Grade and tonnage model of Cyprus massive sulfide, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 131-135.
Singer, D.A., and Mosier, D.L., 1986b, Grade and tonnage model of rhyolite-hosted tin, *in* Cox, D.P., and Singer, D.A., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 169-171.
Singer, D.A., and Mosier, D.L., 1986c, Grade and tonnage model of Kuroko massive sulfide, *in* Cox, D.P., and Singer, D.A., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 190-197.
Singer, D.A., Mosier, D.L., and Cox, D.P., 1986, Grade and tonnage model of porphyry Cu, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 77-81.
Sinno, Y.A., Daggett, P.H., Keller, G.R., Morgan, Paul, and Harder, S.H., 1986, Crustal structure of the southern Rio Grande rift determined from seismic refraction profiling: Journal of Geophysical Research, v. 91, no. B6, p. 6143-6156.
Sivils, D.J., 1992, Preliminary stable isotope analysis of the Late Mississippian Paradise Formation, Big Hatchet Mountains, New Mexico [abs.]: New Mexico Geological Society Proceedings Volume, 1992 Annual Spring Meeting, p. 23. [also New Mexico Geology, v. 14, no. 3, p. 64.]
Small, T.A., 1958, El Cerro de Muleros (Cerro Cristo del Rey), New Mexico and Mexico, *in* Nelson, L.A. and Haigh, B.R., leaders, Franklin and Hueco Mountains, Texas: West Texas Geological Society Fieldtrip Guidebook, p. 68-69.
Smartt, R.A., 1977, The ecology of late Pleistocene and Recent *Microtus* from south-central and southwestern New Mexico: The Southwestern Naturalist, v. 22, no. 1, p. 1-19.
Smartt, R.A., and Harris, A.H., 1979, A record of spruce *(Pinaceae; Picea*) from the Pleistocene of south-central New Mexico: Southwest Naturalist, v. 24, no. 4, p. 710.
Smith, Christian, 1978, Geophysics, geology, and geothermal leasing status of the Lightning Dock KGRA, Animas Valley, New Mexico, *in* Callender, J.F., Wilt, J.C., Clemons, R.E., and James, H.L., eds., Land of Cochise, southeastern Arizona: New Mexico Geological Society, 29th Annual Field Conference, Guidebook, p. 343-348.
Smith, E.I., 1976, Structure and petrology of the John Kerr Peak dome complex, southwestern New Mexico; *in* Elston, W.E., and Northrop, S.A., eds., Cenozoic volcanism in southwestern New Mexico: New Mexico Geological Society Special Publication no. 5, p. 71-78.

Smith, E.I., Aldrich, M.J., Jr., Deal, E.G., and Rhodes, R.C., 1976, Fission-track ages of Tertiary volcanic and plutonic rocks, Mogollon Plateau, southwestern New Mexico, *in* Elston, W.E., and Northrup, S.A., eds., Cenozoic volcanism in southwestern New Mexico: New Mexico Geological Society Special Publication no. 5, p. 117-118.

Smith, E.I., and Rhodes, R.C., 1971, The Mule Creek caldera, a recently discovered felsic volcanic center in southwestern New Mexico [abs.]: Geological Society of America Abstracts, v. 3, no. 2, p. 196.

Smith, E.W., 1982a, Adobe bricks in New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 188, 89 p.

Smith, E.W., 1982b, Large-scale adobe-brick manufacturing in New Mexico, *in* Austin, G.S., compiler, Industrial rocks and minerals of the southwest: New Mexico Bureau of Mines and Mineral Resources Circular 182, p. 49-56.

Smith, E.W., and Austin, G.S., 1989, Adobe, pressed-earth, and rammed-earth industries in New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 127, 60 p.

Smith, F.C., 1987, Geology, mineralization, and exploration potential of the McGhee Peak area, San Simon mining district, Hidalgo County, New Mexico: Albuquerque, University of New Mexico, unpublished Master's thesis, 176 p.

Smith, R.L., and Bailey, R.A., 1969, Resurgent cauldrons: Geological Society of America Memoir 116, p. 613-652.

Smith, T.J., 1981, Barite in the White Sands Missile Range: New Mexico Geology, v. 3, no. 1, p. 1-5.

Smith, T.J., 1982, Geology of barite in New Mexico, *in* Austin, G.S., compiler, Industrial rocks and minerals of the southwest: New Mexico Bureau of Mines and Mineral Resources Circular 182, p. 61-63.

Snow, J.T., and McClelland, T.M., 1990, Dust devils at White Sands Missile Range, New Mexico; 1, Temporal and spatial distributions: Journal of Geophysical Research-D, Atmospheres, v. 95, no. 9, p. 13,708-13,721.

Snyder, J.T., 1986, Heat flow in the southern Mesilla basin with an analysis of the East Potrillo geothermal system: Las Cruces, New Mexico State University, unpublished Master's thesis, 252 p.

Solomon, M., 1976, "Volcanic" massive sulphide deposits and their host rocks--a review and an explanation, *in* Wolf, K.H., ed., Handbook of strata-bound and stratiform ore deposits: Amsterdam, Elsevier Publishing, v. 6, p. 21-54.

Somers, R.E., 1916, Geology of the Burro Mountain copper district, New Mexico: American Institute of Mining Engineers Transactions, v. 52, p. 604-656.

Soulé, J.H., 1946, Exploration of the White Eagle fluorspar mine, Cooke's Peak mining district, Grant County, New Mexico: U.S. Bureau of Mines, Report of Investigations RI-3903, 5 p.

Soulé, J. H., 1948, West Piños Altos Zn-Pb deposits, Grant County, New Mexico: U.S. Bureau of Mines, Report of Investigations, 4237, 8 p.

Soulé, J.H., 1950, Investigation of the Royal John lead-zinc deposits, Grant County, New Mexico: U.S. Bureau of Mines, Report of Investigations 4748, 8 p.

Soulé, J.H., 1951, Investigation of the Torpedo copper deposits--Organ mining district, Doña Ana County, New Mexico: U.S. Bureau of Mines, Investigations Report 4791, 10 p.

Soulé, J.M., 1972, Structural geology of northern part of Animas Mountains, Hidalgo County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 125, 15 p., scale 1: 24,000.

Sorauf, J.E., 1984, Devonian stratigraphy of the San Andres Mountains, Doña Ana, Sierra, and Socorro Counties, New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 189, 32 p.

Soreghan, G.S., 1992, Sedimentology and process stratigraphy of the Upper Pennsylvanian, Pedregosa (Arizona) and Orogrande (New Mexico) basins: Tucson, University of Arizona, unpublished Ph. D. dissertation, 278 p.

Spencer, A.C., and Paige, Sidney, 1935, Geology of the Santa Rita mining area, New Mexico: U.S. Geological Survey Bulletin 859, 11 p.

Staatz, M. H., 1974, Thorium veins in the United States: Economic Geology, v. 69, no. 4, p. 494-507.

Stacey, J.S., and Hedlund, D.C., 1983, Lead-isotopic compositions of diverse igneous rocks and ore deposits from southwestern New Mexico and their implications for early Proterozoic crustal evolution in the western United States: Geological Society of America Bulletin, v. 94, no. 1, p. 43-57.

Stageman, J.C., 1987, Depositional facies and provenance of lower Paleozoic sandstone of the Bliss, El Paso, and Montoya Formations, southern New Mexico and west Texas: Las Cruces, New Mexico State University, unpublished Master's thesis, 101 p.

Stageman, J.C., 1988, Petrography and provenance of Cambro-Ordovician Bliss sandstone, southern New Mexico and west Texas, *in* Mack, G.H., Lawton, T.F., and Lucas, S.G., eds., Cretaceous and Laramide tectonic evolution of southwestern New Mexico: New Mexico Geological Society, 39th Annual Field Conference, Guidebook, p. 123-126.

Sterrett, D.D., 1908, Meerschaum in New Mexico: U.S.Geological Survey Bulletin 340, p. 466-473.

Sterrett, D.B., 1911, Gems and precious stones: U.S. Geological Survey, Mineral Resources for 1909, part 2, p. 791-795.

Stevenson, F.V., 1945, Devonian of New Mexico: Journal of Geology, v. 53, no. 4, p. 217–245.

Stewart, J.H., 1971, Basin and Range structure--a system of horsts and grabens produced by deep-seated extension: Geological Society of America Bulletin, v. 82, p. 1019-1044.

Stewart, J.H., 1978, Basin-range structure in western North America--A review, *in* Smith, R.B., and Eaton, G.P., eds., Cenozoic tectonics and regional geophysics of the western cordillera: Geological Society of America Memoir 152, p. 1-31.

Stewart, T.L., 1988, Plio-Pleistocene diatomites of southeastern Arizona and southwestern New Mexico [abs.]: Abstracts of the New Mexico Academy of Science annual meeting, Farmington; New Mexico Journal of Science, v. 28, no. 2, p. 149.

Stewart, W.J., 1966, New species of the fusulinid genus *Thomsonella* and a proposed change in wall terminology: Journal of Paleontology, v. 40, no. 2, p. 354-358.

Stickel, Roseann, 1988, Preliminary work on the determination of groundwater flow using chemical analysis, Jornada del Muerto Basin, Doña Ana County, New Mexico [abs.]: New Mexico Geology, v. 10, no. 3, p. 66.

Stone, W.J., and Brown, D.R., 1975, Rainfall-runoff relationships for a small semiarid watershed, western flank San Andres Mountains, New Mexico, *in* Seager, W.R., Clemons, R.E., and Callender, J.F., eds., Guidebook of the Las Cruces Country: New Mexico Geological Society, 26th Annual Field Conference, p. 205-212.

Storms, W.R., 1949, Mining methods and costs at the Atwood copper mine, Lordsburg mining district, Hidalgo County, New Mexico: U.S. Bureau of Mines Information Circular 7502, 11 p.

Storms, W.R., and Faust, J.W., 1949, Mining methods and costs at the Kearney zinc-lead mine: U.S. Bureau of Mines, Information Circular, 7507, 11 p.

Stosch, H.G., Jagoutz, E., Carlson, R.W., and Lugmair, G.W., 1979, Mantle differentiation as recorded by ultramafic nodules; oceanic mantle beneath continental crust: Eos, American Geophysical Union, Transactions, v. 60, no. 46, p. 971.

Stoyanow, A.A., 1926, Notes on recent stratigraphic work in Arizona: American Journal of Science, 5th series, v. 12, p. 311–324.

Stoyanow, A.A., 1936, Correlation of Arizona Paleozoic formations: Geological Society of America Bulletin, v. 47, no. 4, p. 459–540.

Stoyanow, A.A., 1937, Fossiliferous zones in the Cretaceous and Tertiary deposits of southwestern Arizona: Geological Society of America Proceedings 1936, p. 296-297 (June, 1936).

Stoyanow, A.A., 1949, Lower Cretaceous stratigraphy in southeastern Arizona: Geological Society of America Memoir 38, 169 p.

Strain, W.S., 1966, Blancan mammalian fauna and Pleistocene formation, Hudspeth County, Texas: Austin, Texas Memorial Museum, Bulletin 10.

Strain, W.S., 1968, Cenozoic rocks in the Mesilla and Hueco bolsons, *in* West Texas Geological Society (Midland, Texas), Delaware basin exploration guidebook, Publication 68-55, p. 83-84.

Strain, W.S., 1969, Late Cenozoic strata of the El Paso-Juarez area (with Spanish abs.), *in* Cordoba, D.A., Wengerd, S.A., and Shomaker, J., eds., Guidebook of the Border Region; Chihuahua and the United States: New Mexico Geological Society, 20th Annual Field Conference, p. 155-157.

Strain, W.S., 1973, Pleistocene sedimentary rocks in the Mesilla bolson: El Paso Geological Society, 7th Annual Fieldguide, p. 33-36.

Strain, W.S., 1976, New formation names in the Cretaceous at Cerro de Cristo Rey, Doña Ana County, New Mexico, *in* Lovejoy, E.M., Geology of Cerro de Cristo Rey Uplift, Chihuahua and New Mexico: New Mexico Bureau of Mines and Mineral Resources Memoir 31, p. 77-82.

Strangway, D.W., Simpson, J., and York, D., 1976, Paleomagnetic studies of volcanic rocks from the Mogollon Plateau area of Arizona and New Mexico, *in* Elston, W.E., and Northrop, S.A., eds., Cenozoic volcanism in southwestern New Mexico: New Mexico Geological Society Special Publication no. 5, p. 119-124.

Stratigraphic Research Committee, 1956, West-east correlation section, San Andres Mountains to New Mexico-Texas line: Roswell Geological Society.

Strongin, Oscar, 1958, Geology and ore deposits of Apache Hills and northern Sierra Rica, Hidalgo County, New Mexico: New York, Columbia University, unpublished Ph. D. dissertation, 221 p. (New Mexico Bureau of Mines and Mineral Resource Open-file Report 18)

Stuart, C.J., 1981, Hunt's Hole maar volcano, Doña Ana County, south-central New Mexico: El Paso Geological Society, Guidebook, p. 64-72.

Stuart, C.J., and Brenner, M.G., 1979, "Low-regime" base surge dunes--An example from Kilbourne and Hunt's holes, south-central New Mexico [abs.]: Geological Society of America Abstracts with Programs, v. 11, no. 7, p. 525.

Sully, J.M., 1908, Report on property of Santa Rita Company situated in Grant County, New Mexico: unpublished report on file at New Mexico Bureau of Mines and Mineral Resources, 96 p.

Summers, W.K., 1965a, Chemical characteristics of New Mexico's thermal waters--a critique: New Mexico Bureau of Mines and Mineral Resources Circular 83, 27 p.

Summers, W.K., 1965b, A preliminary report on New Mexico's geothermal energy resources: New Mexico Bureau of Mines and Mineral Resources Circular 80, 41 p., 1 plate.

Summers, W.K., 1968, Geothermics--New Mexico's untapped resource: New Mexico Bureau of Mines and Mineral Resources Circular 98, 9 p.

Summers, W.K., 1976, Catalog of thermal waters in New Mexico: New Mexico Bureau of Mines and Mineral Resources Hydrologic Report 4, 80 p., chemical analyses on microfiche.

Surdam, R.C., and Sheppard, R.A., 1978, Zeolites in saline, alkaline lake deposits, *in* Sand, L.B., and Mumpton, F.A., eds., Natural zeolites: Occurrence, properties, use: Elmsford, N.Y., Pergamon Press, p. 145-174.

Sutton, Victoria, and Morse, E.L., 1988, Hydrogeologic investigation at White Sands Test Facility (WSTF), Las Cruces, New Mexico [abs.]: New Mexico Geology, v. 10, no. 3, p. 66.

Swanberg, C.A., 1975a, Application of chemical geothermometers to thermal waters of southwest New Mexico and West Texas [abs.]: American Association of Petroleum Geologists Bulletin, v. 59, no. 5, p. 924.

Swanberg, C.A., 1975b, Detection of geothermal components in groundwaters of Doña Ana County, southern Rio Grande rift, New Mexico, *in* Seager, W.R., Clemons, R.E., and Callender, J.F., eds., Guidebook of the Las Cruces Country: New Mexico Geological Society, 26th Annual Field Conference, p. 175-180.

Swanberg, C.A., 1978, Chemistry, origin and potential of geothermal resources in southwestern New Mexico and southeastern Arizona, *in* Callender, J.F., Wilt, J.C., Clemons, R.E., and James, H.L., eds., Land of Cochise, southeastern Arizona: New Mexico Geological Society with the Arizona Geological Society, 29th Field Conference, Guidebook, p. 349-351.

Swanberg, C.A., 1979, Chemistry of thermal and non-thermal groundwaters in the Rio Grande rift and adjacent tectonic provinces, *in* Riecker, R.E., ed., Rio Grande rift--Tectonics and magmatism (2nd ed.): Washington, D.C., American Geophysical Union, p. 274-288.

Swanberg, C.A., 1982, Deep thermal structure of Mimbres Basin, New Mexico--Implications for oil and gas potential [abs.]: American Association of Petroleum Geologists Bulletin, v. 66, no. 10, p. 1701.

Swanberg, C.A., 1983a, Geothermal resources of rifts--A comparison of the Rio Grande rift and the Salton trough: Tectonophysics, v. 94, p. 659-678.

Swanberg, C.A., 1983b, The geothermal resources of New Mexico: New Mexico State University Energy Institute, Map, scale 1:500,000.

Swanberg, C.A., Sander, R., Marvin, P.R., Daggett, P., Young, C.T., and Morgan, P., 1981, Geophysical/geothermal studies in the southeastern Mimbres Basin near the City of Columbus, southern Rio Grande Rift, New Mexico, *in* Hoffer, J.M., and Hoffer, R.L., eds., Geology of the border; southern New Mexico-northern Chihuahua: El Paso Geological Society, p. 91-96.

Sweet, W.C., 1977, Conodont biostratigraphy of the late Ordovician Montoya Group, Texas and New Mexico [abs.]: Geological Society of America Abstracts with Programs, v. 9, no. 1, p. 76.

Sykes, L.R., 1978, Intraplate seismicity, reactivation of preexisting zones of weakness, alkaline magmatism, and other tectonism postdating continental fragmentation: Reviews, Geophysics and Space Physics, v. 16, 621-688.

Talmage, S.B., and Wootton, T.P., 1937, The non-metallic mineral resources of New Mexico and their economic features (exclusive of fuels): New Mexico Bureau of Mines and Mineral Resources Bulletin 12, p. 151-152.

Taylor, A.M., 1967, Geohydrologic investigations in the Mesilla Valley, New Mexico: Las Cruces, New Mexico State University, unpublished Master's thesis, 130 p.

Taylor, D.W., 1985, *Pecosorbis*, a new genus of fresh-water snails (Planorbidae) from New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 194, 17 p.
Telford, W.M., Geldart, L.P., Sheriff, R.E., and Keys, D.A., 1976, Applied geophysics: New York, Cambridge University Press, 860 p.
Templain, C.J., and Dotterrer, R.E., 1978, Preliminary study of the uranium favorability of the Hornada del Muerto Basin and adjacent areas, south-central New Mexico: Department of Energy Report GJBX 80-78, 22 p.
Teng, W.L., 1984, Remote sensing for landforms and soils in the arid southwest United States: Ithaca, Cornell University, unpublished Ph. D. dissertation, 404 p.
Texas Instruments, Inc., 1979, Aerial radiometric and magnetic reconnaissance survey of portions of Arizona-New Mexico, Clifton, Douglas, Mesa, Nogales, Tucson, and Silver City quadrangles: U.S. Department of Energy, Grand Junction Office Report GJBX-23(79), 7 vols.
Theis, C.V., 1991a, Ground-water conditions near Deming, New Mexico, *in* Theis, C.V., ed., Short papers on water resources in New Mexico, 1937-1957: U.S. Geological Survey Open-File Report 91-0081, p. 16-18.
Theis, C.V., 1991b, Ground-water conditions near Separ, New Mexico, *in* Theis, C.V., ed., Short papers on water resources in New Mexico 1937-1957: U.S. Geological Survey Open-File Report 91-0081, p. 42-44.
Theis, C.V., 1991c, Memorandum no. 2 on ground-water supplies in the vicinity of Ft. Bayard, New Mexico, *in* Theis, C.V., ed., Short papers on water resources in New Mexico 1937-1957: U.S. Geological Survey Open-File Report 91-0081, p. 60-62.
Theis, C.V., 1991d, Memorandum no. 3 on the pumping test of the Army test well on Mracek land near Silver City, New Mexico, *in* Theis, C.V., ed., Short papers on water resources in New Mexico 1937-1957: U.S. Geological Survey Open-File Report 91-0081, p. 49-51.
Theis, C.V., 1991e, ed., Short papers on water resources in New Mexico 1937-1957: U.S. Geological Survey Open-File Report 91-0081, 77 p.
Theodore, T.G., 1986, Descriptive model of porphyry Mo, low F, *in* Cox, D.P., and Singer, D.A., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 120-121.
Thomman, W.F., 1981, Ignimbrites, trachytes, and sedimentary rocks of the Precambrian Thunderbird Group, Franklin Mountains, El Paso, Texas: Geological Society of America Bulletin, v. 92, no. 2, p. 94-100.
Thomman, W.F., 1991, Petrology of the middle Proterozoic Thunderbird Group, Franklin Mountains, El Paso, Texas, *in* Julian, Betsy, and Zidek, Jiri, Field guide to geologic excursions in New Mexico and adjacent areas of Texas and Colorado: New Mexico Bureau of Mines and Mineral Resources Bulletin 137, p. 5-7.
Thompson, A.J., 1965a, Lead, *in* Mineral and water resources of New Mexico: U.S. Congress, 89th, 1st session, Senate Committee on Interior and Insular Affairs: New Mexico Bureau of Mines and Mineral Resources Bulletin 87, p. 149-154.
Thompson, A.J., 1965b, Zinc, *in* Mineral and water resources of New Mexico: U.S. Congress, 89th, 1st session, Senate Committee on Interior and Insular Affairs: New Mexico Bureau of Mines and Mineral Resources Bulletin 87, p. 154-159.
Thompson, M.L., 1948, Studies of American fusulinids: University of Kansas Paleontological Contributions No. 4, Protozoa, Article 1.
Thompson, M.L., 1954, American Wolfcampian fusulinids: University of Kansas Paleontology Contribution No. 14, Protozoa, Article 5, --- p.
Thompson, Sam, III, 1976, Tectonic and igneous effects on petroleum accumulations in southwestern New Mexico: New Mexico Geological Society Special Publication 6, p. 122-126.

Thompson, Sam, III, 1977a, compiler, Geology, petroleum source rocks, and thermal metamorphism in KCM No.1 Forest Federal well, Hidalgo Country, New Mexico: Socorro, New Mexico Bureau Mines and Mineral Resources Circular 152, 62 p.

Thompson, Sam, III, 1977b, Subsurface geology and the petroleum-exploration significance of KCM No. 1 Forest Federal Well, Hidalgo County, New Mexico, *in* Thompson, Sam, III, compiler, Geology, petroleum source rocks, and thermal metamorphism in KCM No. 1 Forest Federal well, Hidalgo County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 152, p. 5-23.

Thompson, S., III, 1980a, Oil and gas exploration wells in Pedregosa Basin [abs.]: New Mexico Geology, v. 2, no. 4, p. 63.

Thompson, S., III, 1980b, Pedregosa basin's main exploration target is Pennsylvanian dolostone: Oil and Gas Journal, v. 78, no. 42, p. 202, 207, 210, 215.

Thompson, Sam, 1981a, Analyses of petroleum source and reservoir rocks in southwestern New Mexico : petroleum source rocks in exploration wells drilled to Paleozoic or Mesozoic units, Hidalgo and Grant counties, New Mexico--Final report (1/1/78-8/31/81): New Mexico Energy Research and Development Institute.

Thompson, Sam, III, 1981b, Petroleum source rocks in exploration wells drilled to Paleozoic or Mesozoic units, Hidalgo and Grant Co., New Mexico: Socorro, New Mexico Bureau Mines and Mineral Resources Open-File Report 153, 126 p.

Thompson, S., III, 1982a, Oil and gas exploration wells in southwestern New Mexico, *in* Powers, R.B., ed., Geologic studies of the Cordilleran thrust belt: Rocky Mountain Association of Geologists, p. 521-536.

Thompson, S., III, 1982b, Petroleum exploration in Pedregosa Basin, southwestern New Mexico: American Association of Petroleum Geologists Bulletin, v. 66, no. 2, p. 248.

Thompson, S. III, and Bieberman, R.A., 1975, Oil and gas exploration wells in Doña Ana County, *in* Seager, W.R., Clemons, R.E., and Callender, J.F., eds., Guidebook of the Las Cruces Country: New Mexico Geological Society, 26th Annual Field Conference, p. 171-174.

Thompson, Sam, III, and Jacka, A.D., 1981, Pennsylvanian stratigraphy, petrography, and petroleum geology of Big Hatchet Peak section, Hidalgo County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 176, 125 p.

Thompson, S., III, and Potter, P.E., 1981, Paleocurrents of Bliss Sandstone (Cambrian-Ordovician), southwestern New Mexico and western Texas: New Mexico Bureau of Mines and Mineral Resources Annual Report, p. 36-51.

Thompson, S., III, Tovar, R.J.C., and Conley, J.N., 1978, Oil and gas exploration wells in the Pedregosa Basin, *in* Callender, J.F., Wilt, J.C., and Clemons, R.E., eds., Land of Cochise, Southeastern Arizona: New Mexico Geological Society, *in cooperation with* Arizona Geological Society, 29th Field Conference, p. 331-342.

Thorman, C.H., 1977, Geologic map of the Coyote Peak and Brockman quadrangles, Hidalgo and Grant Counties, New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map MF-924, scale 1:24,000.

Thorman, C.H., and Drewes, Harald, 1978a, Cretaceous-early Tertiary history of the northern Pyramid Mountains, southwestern New Mexico, *in* Callender, J.F., Wilt, J.C., and Clemons, R.E., eds., Land of Cochise, Southeastern Arizona: New Mexico Geological Society, *in cooperation with* Arizona Geological Society, 29th Field Conference, p. 215-218.

Thorman, C.H., and Drewes, Harald, 1978b, Geologic map of the Gary and Lordsburg quadrangles, Hidalgo County, New Mexico: U.S. Geological Survey Miscellaneous Investigations Series Map I-1151, scale 1:24,000.

Thorman, C.H., and Drewes, Harald, 1978c, Geologic map of the Saltys quadrangle, Grant County, New Mexico: U.S. Geological Survey Miscellaneous Investigations Series Map I-1137, scale 1:24,000.
Thorman, C.H., and Drewes, Harald, 1979, Geologic map of the Grandmother Mountain East and Grandmother Mountains West quadrangles, New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map MF-1088, scale 1:24,000.
Thorman, C.H., and Drewes, Harald, 1980, Geologic map of the Victorio Mountains, Luna County, southwestern New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map MF-1175, scale 1:24,000. [Published in 1978 as U.S. Geological Survey Miscellaneous Field Studies Map MF-1175, scale 1:24,000.]
Thorman, C.H., and Drewes, Harald, 1981, Geologic map of the Gage SW quadrangle, Grant and Luna Counties, New Mexico: U.S. Geological Survey Miscellaneous Investigations Series Map I-1231, scale 1:24,000.
Thorne, H.A., 1931, Mining practice at the Chino mines, Nevada Consolidated Copper, Co., Santa Rita, New Mexico: U.S. Bureau of Mines Information Circular 6412, 29 p.
Thorpe, R.I., and Franklin, J.M., 1984, Chemical-sediment-hosted gold, *in* Eckstrand, O.R., ed., Canadian mineral deposit types--a geological synopsis: Geological Survey of Canada Economic Geology Report 36, p. 29.
Titley, S.R., 1981, Geologic and geotectonic setting of porphyry copper deposits in the southern Cordillera, *in* Dickinson, W.R., and Payne, W.D., Relations of tectonics to ore deposits in the southern Cordillera: Arizona Geological Society Digest, v. 14, p. 79-98.
Titley, S.R., Anzalone, S.A., and Anthony, E.Y., 1989, IGC field trip T338--Porphyry copper deposits in the American Southwest: International Geological Congress, 28th, Field Trip Guidebook T338, 26 p.
Titley, S.R., and Beane, R.E., 1981, Porphyry copper deposits; part I, Geologic settings, alteration, and mineralization: Economic Geology, Seventy-fifth Anniversary Volume, p. 235-269.
Todd, V.R., Silberman, M.L., and Armstrong, A.K., 1975, Geochemistry, petrology, and K-Ar ages of igneous rocks in the central Peloncillo Mountains, Hidalgo County, New Mexico [abs.]: New Mexico Geological Society and Arizona Geological Society, Symposium on base-metal and precious-metal districts of New Mexico and Arizona, p. 25-26.
Tooker, E.W., and Vercoutere, T.L., 1986, Gold in the conterminous United States, perspective of 1986—Preliminary map of selected geographic, economic, and geologic attributes of productive (>10,000 oz) gold districts: U.S. Geological Survey Open-File Report 86-209, 32 p.
Tourtelot, E.B., and Meier, A.L., 1976, Lithium in the Gila Conglomerate, southwestern New Mexico, *in* Vine, J.D., ed., Lithium resources and requirements by the year 2000: U.S. Geological Survey Professional Paper 1005, p. 123-127.
Towle, J.N., and Fitterman, D.V., 1975, Geomagnetic variations at Kilbourne Hole, New Mexico, *in* Seager, W.R., Clemons, R.E., and Callender, J.F., eds., Guidebook of the Las Cruces Country: New Mexico Geological Society, 26th Annual Field Conference, p. 281.
Trauger, F.D., 1965, Geologic structure pattern of Grant County, New Mexico, *in* Fitzsimmons, J.P., and Lochman-Balk, Christina, eds., Guidebook of southwestern New Mexico II: New Mexico Geological Society, 16th Field Conference, p. 184-187.
Trauger, F.D., 1972, Water resources and general geology of Grant County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Hydrologic Report 2, 211 p.
Trauger, F.D., and Doty, G.C., 1965, Ground water--Its occurrence and relation to the economy and geology of southwestern New Mexico, *in* Fitzsimmons, J.P., and Lochman-Balk, Christina, eds., Guidebook of southwestern New Mexico II: New Mexico Geological Society, 16th Field Conference, p. 215-227.

Tschernich, R.W., 1992, Zeolites of the world: Phoenix, Arizona, Geoscience Press, Inc., 563 p.
Turner, D.R., 1990, Geochemistry, stable isotopes, and fluid flow of the Empire zinc skarns, Central mining district, Grant County, New Mexico: unpubl. PhD. dissertation, University of Utah, Salt Lake City, 295 pp.
Turner, D.R., and Bowman, J.R., 1988, Modeling of temperature-fluid flow regimes in the Empire Zn-skarns, Hanover, N. Mex. [abs.]: Geological Society of America Abstracts with Programs, v. 20, no. 7, p. 93.
Turner, D.R. and Bowman, J.R., 1993, Origin and evolution of skarn fluids, Empire zinc skarns, Central mining district, New Mexico, U.S.A.: Applied Geochemistry, v. 8, pp. 9-36.
Turner, G.L., 1962, The Deming axis, southeastern Arizona, New Mexico, and Trans-Pecos Texas, *in* Weber, R.H., and Pierce, H.W., eds., Mogollon Rim Region (east-central Arizona): New Mexico Geological Society in cooperation with the Arizona Geological Society, 13th Annual Field Conference, Guidebook, p. 59-71.
Tweto, Ogden, 1975, Laramide (Late Cretaceous-early Tertiary) orogeny in the southern Rocky Mountains, *in* Curtis, B.F., ed., Cenozoic history of the southern Rocky Mountains: Geological Society of America Memoir 144, p. 1-44.
U.S. Bureau of Mines, 1927-1990, Mineral yearbook: Washington, D.C., U.S. Government Printing Office, variously paginated.
U.S. Bureau of Mines, 1992, Mineral commodity summaries 1992: U.S. Bureau of Mines, 204 p.
U.S. Bureau of Mines, 1994, Mineral commodity summaries 1994: Washington, D.C., U.S. Government Printing Office.
U.S. Bureau of Mines, 1995, "Manganese" *in* Mineral Industry Surveys, March 1995.
U.S. Department of Energy, 1979, Aerial radiometric and magnetic reconnaissance survey of portions of Arizona-New Mexico Douglas quadrangle: U.S. Department of Energy Open-file Report GJBX-23(79), v. 2-F.
U.S. Geological Survey, 1902-1927, Mineral resources of the United States (1901-1923): Washington, D.C., U.S. Government Printing Office, variously paginated.
U.S. Geological Survey, 1972, Aeromagnetic map of the Morenci-Monticello area, southeastern Arizona and southwestern New Mexico: U.S. Geological Survey Geophysical Investigations Map GP-0838.
U.S. Geological Survey, 1979, Aeromagnetic map of the north and west parts of the Silver City 1°x2° quadrangle, Arizona and New Mexico: U.S. Geological Survey Open-File Report-79-0708.
U.S. Geological Survey, 1980, Aeromagnetic map of the southern part of the Silver City 1°x2° quadrangle, Arizona and New Mexico: U.S. Geological Survey Open-File Report 80-1128.
U.S. Geological Survey, 1985a, Land use and land cover and associated maps for Douglas, Arizona; New Mexico: U.S. Geological Survey Open-File Report 84-0316.
U.S. Geological Survey, 1985b, Land use and land cover and associated maps for El Paso Texas; New Mexico: U.S. Geological Survey Open-File Report 84-0539.
U.S. Geological Survey, 1985c, Land use and land cover and associated maps for Las Cruces, New Mexico: U.S. Geological Survey Open-File Report 85-0057.
U.S. Geological Survey, 1987a, Aeromagnetic map of the Big Hatchet Mountains and vicinity, southwestern New Mexico: U.S. Geological Survey Open-File Report 87-0335.
U.S. Geological Survey, 1987b, Aeromagnetic map of the Buck Robinson Peak area, Arizona and New Mexico: U.S. Geological Survey Open-File Report 80-0995.

U.S. Geological Survey, *in collaboration with* New Mexico Bureau of Mines and Mineral Resources, 1965, New Mexico: Report to the Committee on Interior and Insular Affairs, U.S. Senate, 437 p.

Union Carbide Corporation, 1981a, Hydrogeochemical and stream sediment basic data for Douglas quadrangle, Arizona; New Mexico: Oak Ridge Gaseous Diffusion Plant, Oak Ridge, Tennessee, Report Number GJBX 244-81, and K/UR 315; 57 p.

Union Carbide Corporation, 1981b, Hydrogeochemical and stream sediment reconnaissance data for Clifton quadrangle, New Mexico: Oak Ridge Gaseous Diffusion Plant, Oak Ridge, Tennessee, Report Number GJBX 359-81, and K/UR 369; 129 p.

Union Carbide Corporation, 1981c, Hydrogeochemical and stream sediment reconnaissance data for Las Cruces quadrangle, New Mexico: Oak Ridge Gaseous Diffusion Plant, Oak Ridge, Tennessee, Report Number GJBX 416-81, and K/UR 391, 203 p.

Updegraff, C.D., and Gelhar, L.W., 1978, Parameter estimation for a lumped-parameter ground-water model of the Mesilla Valley, New Mexico; technical completion report: New Mexico Institute of Mining and Technology Water Resources Institute Report 97, p. 69.

Uphoff, T.L., 1978, Subsurface stratigraphy and structure of the Mesilla and Hueco bolsons, El Paso region, Texas and New Mexico: El Paso, University of Texas, Master's thesis, unknown p.

Uphoff, T.L., 1979, Late Cretaceous-Paleogene tectonic activity of the El Paso region, Texas and New Mexico [abs.]: Geological Society of America Abstracts with Programs, v. 11, no. 6, p. 304.

Utada, Minoru, 1970, Occurrence and distribution of authigenic zeolites in the Neogene pyroclastic rocks in Japan: Tokyo University College of General Science, Scientific Papers, v. 20, p. 191-262.

Utada, Minoru, and Vine, J.D., 1984, Zonal distribution of zeolites and authigenic plagioclase, Spanish Peaks region, southern Colorado, *in* Olson, David, and Bisio, Attilio, eds., Proceedings of the Sixth International Zeolite Conference: Guildford, U.K., Butterworths, p. 604-662.

VandenHuevel, R.C., 1964, The occurrence of sepiolite and attapulgite in a calcareous soil near Las Cruces, New Mexico [abs.]: Program and abstracts; Annual Clay Mineral Conference, v. 1, p. 29-30.

VandenHuevel, R.C., 1966, The occurrence of sepiolite and attapulgite in a calcareous soil near Las Cruces, New Mexico: Clays and Clay Minerals, v. 13: Pergamon Press International Series Monographs in Earth Science, v. 25, p. 193-207.

Vanderhill, J.B., 1986, Lithostratigraphy, vertebrate paleontology, and magnetostratigraphy of Plio-Pleistocene sediments in the Mesilla Basin, New Mexico: Austin, University of Texas, unpublished Ph. D. dissertation, 330 p.

VanDerSpuy, P.M., 1975, Geology and geochemical investigation of geophysical anomalies, Sierra Rica, Hidalgo County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Open File Report 62, --- p. [also unpublished Master's thesis, Golden, Colorado School of Mines, 1970].

VanDevender, T.R., and Everitt, B.L., 1977, The latest Pleistocene and Recent vegetation of the Bishop's Cap, south-central New Mexico: The Southwestern Naturalist, v. 22, no. 3, p. 337-352.

Varnell, R., 1976, Geology of the Hat Top Quadrangle, Luna County, New Mexico: El Paso, University of Texas, unpublished Master's thesis, 62 p.

Von Bargen, D.J., 1979, The silver-antimony-mercury system and the mineralogy of the Black Hawk District, New Mexico: Lafayette, Ind., Purdue University, unpublished Ph. D. dissertation, 260 p.

Von Bargen, D.J., 1993, Minerals of the Black Hawk district, New Mexico: Rocks and Minerals, v. 68, no. 2, p. 96-111, 132-133.
Wade, W.R., 1913, Minerals of the Tres Hermanas district: Engineering and Mining Journal, v. 96, p. 589-590.
Wade, W.R., 1914, Apache mining district, New Mexico: Engineering and Mining Journal, v. 87, no. 12, p. 597.
Wahl, D.E., 1980, Mid-Tertiary volcanic geology in parts of Greenlee County, Arizona, Grant and Hidalgo Counties, New Mexico: Tempe, Arizona State University, unpublished Ph. D. dissertation, 144 p.
Waldschmidt, W. A., and Lloyd, E. R., eds., 1949, Geology and ore deposits of Silver City Region, New Mexico: West Texas Geological Society and Southwestern New Mexico Section, American Institute of Mining and Metallurgical Engineers Guidebook, Field trip no. 3, 45 p.
Walker, Dan, 1986, Depositional environments of the Hayner Ranch and Rincon Valley formations (Miocene), Tonuco Uplift, south-central New Mexico: Compass of Sigma Gamma Epison, v. 64, no. 1, p. 30-38.
Walker, Dan, and Mack, G.H., 1985, Tectonics and dispersal of Miocene rift-fill sediments, southern New Mexico: American Association of Petroleum Geologists Bulletin, v. 69, no. 2, p. 314.
Wallin, E.T., 1983, Stratigraphy and paleoenvironments of the Engle Coal Field, Sierra County, New Mexico: Socorro, New Mexico Technical University, unpublished Master's thesis, 127 p.
Walper, J.L., 1977, Paleozoic tectonics of the southern margin of North America: Gulf Coast Association Geological Society Transactions, v. 27, p. 230-241.
Walton, A.W., Salter, T.L., and Zetterlund, D., 1980, Uranium potential of southwestern New Mexico (southern Hidalgo County), including observations on crystallization, history of lavas and ash tuffs and the release of uranium from them: U.S. Department of Energy, Report GJBX-169-80, 114 p.
Wargo, J.G., 1959, Geology of the Schoolhouse Mountain quadrangle, Grant County, New Mexico: Tucson, University of Arizona, unpublished Ph. D. dissertation, 187 p.
Warner, L.A., Holser, W.T., Wilmarth, V.R., and Cameron, E.N., 1959, Occurrence of nonpegmatite beryllium in the United States: U.S. Geological Survey Professional Paper 318, 198 p.
Wasilewski, P., and Mayhew, M.A., 1982, Crustal xenolith magnetic properties and long wavelength anomaly source requirements: Geophysical Research Letters, v. 9, no. 4, p. 329-332.
Wasilewski, P.J., and Padovani, E.R., 1981, Crustal magnetization beneath the Rio Grande Rift based on xenoliths from Kilbourne Hole and Potrillo Maar--Papers presented to the Conference on the processes of planetary rifting: Lunar and Planetary Institute Contribution 457, p. 153-155.
Watts, K.C., 1981 (1982), Geochemical anomalies, Silver City 1°x2° quadrangle, Arizona, New Mexico, *in* Geological Survey Research 1981: U.S. Geological Survey Professional Paper, p. 15-16.
Watts, K.C., Carpenter, R.H., Chao, T.T., Hassemer, J.R., and Sanzolone, R.F., 1983, Comparison of secondary Fe-Mn oxides in fracture coatings and heavy-mineral concentrates as sampling media, Silver City mining region, New Mexico: Mining Engineering, v. 35, no. 8, p. 1177-1184.

Watts, K.C., and Hassemer, J.R., 1980, Distribution and abundance of fluorite in stream-sediment concentrates, Silver City 1°x2° quadrangle, Arizona and New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map MF 1183-C.

Watts, K.C., and Hassemer, J.R., 1988, Geochemical interpretative and summary maps, Silver City 1°x2° quadrangle, New Mexico and Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map I-1310-E.

Watts, K.C., Hassemer, J.R., and Day, G.W., 1983, Geochemical maps of Bunk Robinson Peak and Whitmire Canyon Roadless Areas, Hidalgo County, New Mexico, and Cochise County, Arizona: U.S. Geological Survey Miscellaneous Field Studies Map MF-1425-C, scale 1: 62,500.

Watts, K.C., Hassemer, J.R., Forn, C.L., and Siems, D.F., 1986a, Geochemical maps showing distribution and abundance of lead in two fractions of stream-sediment concentrates, Silver City 1°x2° quadrangle, New Mexico and Arizona: U.S. Geological Survey Miscellaneous Field Studies Map MF-1183-A.

Watts, K.C., Hassemer, J.R., Forn, C.L., and Siems, D.F., 1986b, Geochemical maps showing distribution and abundance of copper in two fractions of stream-sediment concentrates, Silver City 1°x2° quadrangle, New Mexico and Arizona: U.S. Geological Survey Miscellaneous Field Studies Map MF-1183-B.

Watts, K.C., Hassemer, J.R., Forn, C.L., and Siems, D.F., 1986d, Geochemical maps showing distribution and abundance of zinc in two fractions of stream-sediment concentrates, Silver City 1°x2° quadrangle, New Mexico and Arizona: U.S. Geological Survey Miscellaneous Field Studies Map MF-1183-D.

Watts, K.C., Hassemer, J.R., Forn, C.L., and Siems, D.F., 1986e, Geochemical maps showing distribution and abundance of molybdenum in two fractions of stream-sediment concentrates, Silver City 1°x2° quadrangle, New Mexico and Arizona: U.S. Geological Survey Miscellaneous Field Studies Map MF-1183-E.

Watts, K.C., Hassemer, J.R., Forn, C.L., and Siems, D.F., 1986f, Geochemical maps showing distribution and abundance of silver in two fractions of stream-sediment concentrates, Silver City 1°x2° quadrangle, New Mexico and Arizona: U.S. Geological Survey Miscellaneous Field Studies Map MF-1183-F.

Watts, K.C., Hassemer, J.R., Forn, C.L., and Siems, D.F., 1986g, Geochemical maps showing distribution and abundance of tungsten in two fractions of stream-sediment concentrates, Silver City 1°x2° quadrangle, New Mexico and Arizona: U.S. Geological Survey Miscellaneous Field Studies Map MF-1183-G.

Watts, K.C., Hassemer, J.R., Forn, C.L., and Siems, D.F., 1986h, Geochemical maps showing distribution and abundance of bismuth in two fractions of stream-sediment concentrates, Silver City 1°x2° quadrangle, New Mexico and Arizona: U.S. Geological Survey Miscellaneous Field Studies Map MF-1183-H.

Watts, K.C., Hassemer, J.R., Forn, C.L., and Siems, D.F., 1986i, Geochemical maps showing distribution and abundance of tin in two fractions of stream-sediment concentrates, Silver City 1°x2° quadrangle, New Mexico and Arizona: U.S. Geological Survey Miscellaneous Field Studies Map MF-1183-I.

Watts, K.C., Hassemer, J.R., Forn, C.L., and Siems, D.F., 1986j, Geochemical maps showing distribution and abundance of manganese in two fractions of stream-sediment concentrates, Silver City 1°x2° quadrangle, New Mexico and Arizona: U.S. Geological Survey Miscellaneous Field Studies Map MF-1183-J.

Watts, K.C., Hassemer, J.R., Forn, C.L., and Siems, D.F., 1986k, Geochemical maps showing distribution and abundance of barium in two fractions of stream-sediment concentrates,

Silver City 1°x2° quadrangle, New Mexico and Arizona: U.S. Geological Survey Miscellaneous Field Studies Map MF-1183-K.
Watts, K.C., Hassemer, J.R., Siems, D.F., and Nishi, J.M., 1978, A statistical summary and listing of the spectrographic analyses of heavy mineral concentrates and conventional, sieved stream-sediment samples, Silver City area, New Mexico: U.S. Geological Survey Open-File Report 78-0801, 247 p.
Weber, R.H., 1965, Lightweight aggregates; in Mineral and Water Resources of New Mexico: U.S. Congress, 89th, 1st session, Senate Committee on Interior and Insular Affairs: New Mexico Bureau of Mines and Mineral Resources Bulletin 87, p. 332-344.
Weber, R.H., 1980a, City of Rocks: New Mexico Geology, v. 2, no. 1, p. 10-11.
Weber, R.H., 1980b, Rock Hound: New Mexico Geology, v. 2, no. 4, p. 59-60.
Weber, R.H., and Bassett, W.A., 1963, K-Ar ages of Tertiary volcanic and intrusive rocks in Socorro, Catron, and Grant Counties, New Mexico, *in* Kuellmer, F.J., ed., Socorro Region: New Mexico Geological Society, 14th Annual Field Conference, Guidebook, p. 220-223.
Weber, R.H., and Kottlowski, F.E., 1959, Gypsum resources of New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 68, 68 p.
Weber, R.H., and Willard, M.E., 1959, Reconnaissance geologic map of Mogollon 30-minute quadrangle: New Mexico Bureau of Mines and Mineral Resources Geologic Map 10, scale 1:126,720.
Webring, M.W., 1981, MINC: A gridding program based on minimum curvature: U.S. Geological Survey Open-File Report 81-1224, 41 p.
Weed, W.H., 1901, The El Paso tin deposits: U.S. Geological Survey Bulletin 178, 15 p.
Weise, J.R., 1982a, Stratigraphy, lithofacies, and biofacies of the U-Bar Formation (Aptian-Albian) of the Big Hatchet Mountains, Hidalgo County, New Mexico: El Paso, University of Texas, unpublished Ph. D. dissertation, 403 p.
Weise, J.R., 1982b, Stratigraphy, petrography, and calcareous microfossils of the limestone-shale member, U-Bar Formation, Big Hatchet Mountains, Hidalgo County, New Mexico [abs.]: New Mexico Geology, v. 4, no. 1, p. 13.
Weissenborn, 1948, A new occurrence of helvite: American Mineralogist, v. 33, nos. 9-10, p.648-649.
Wells, E.H., 1918, Manganese in New Mexico: New Mexico State School of Mines Bulletin 2, 85 p.
Wells, E.H., and Wootton, T.P., 1932, *revised by* Wootton, T.P., Gold mining and gold deposits in New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 5, 24 p.
Wells, E.H., and Wootton, T.P, 1940, Gold mining and gold deposits in New Mexico (revised ed.): New Mexico Bureau of Mines and Mineral Resources Circular 5, 25 p.
Wells, J.L., 1909, Mines of the Lordsburg district, New Mexico: Engineering and Mining Journal, v. 87, p. 890.
Welsh, N.J., 1914, The Organ mining district: Engineering and Mining Journal, v. 98, p. 331-334.
Wengard, S.A., 1962, Regional structural-stratigraphic cross section, east-central Arizona to west-central New Mexico, *in* Weber, R.H., and Pierce, H.W., eds., Mogollon Rim Region (east-central Arizona): New Mexico Geological Society in cooperation with the Arizona Geological Society, 13th Annual Field Conference, Guidebook, p. 58.
Wengerd, S.A., 1969, Geologic history and the exploration for oil in the border region, *in* Cordoba, D.A., Wengerd, S.A., and Shomaker, J., eds., Guidebook of the Border Region; Chihuahua and the United States: New Mexico Geological Society, 20th Annual Field Conference, p. 197-204.

Wengerd, S.A., 1970, Petroleum prospects in southwesternmost New Mexico, *in* Woodward, L.A., ed., Guidebook of the Tyrone-Big Hatchet Mountains-Florida Mountains Region: New Mexico Geological Society, 21st Annual Field Conference, p. 91-104.

Wertz, J.B., 1970a, Arizona's copper province and the Texas lineament: Mining engineering, v. 5, p. 80-81.

Wertz, J.B., 1970b, The Texas lineament and its economic significance in southeastern Arizona: Economic Geology, v. 65, p. 166-181.

West, A.M., Lawton, T.F., Mack, G.H., and Clemons, R.E., 1993, Subsurface stratigraphy of Pennsylvanian strata beneath the Jornada del Muerto, south-central New Mexico [abs.]: Proceedings, New Mexico Geological Society Annual Spring Meeting, Socorro, p. 71.

White, D.E., 1981, Active geothermal systems and hydrothermal ore deposits, *in* Skinner, B.J., ed., Economic Geology, Seventy-Fifth Anniversary Volume, 1905-1980: Economic Geology Publishing Company, p. 392-423.

White, D.E., 1983, Summary of hydrologic information in the El Paso, Texas, area, with emphasis on ground-water studies, 1903-80: U.S. Geological Survey Open-File Report 83-0775, 100 p.

White, D.E., and Williams, D.L., eds., 1975, Assessment of Geothermal Resources of the United States, 1975: U.S. Geological Survey Circular 726, 155 p.

White, D.L., and Foster, M.G., 1981, Uranium resource evaluation, Clifton quadrangle, Arizona and New Mexico: U.S. Department of Energy, Report PGJ/F-116-82, 53 p.

White, D.L., and Foster, M., 1982, Clifton quadrangle, Arizona and New Mexico: Bendix Field Engineering Corporation, Grand Junction Operation PGJ/F-116(82), 49 p.

White, N.C., and Hedenquist, J.W., 1990, Epithermal environments and styles of mineralization--variations and their causes and guidelines for exploration: Journal of Geochemical Exploration v. 36, no. 3, p. 445-474.

Wierenga, P.J., Hudson, D.B., Hills, R.G., Porro, I., Kirkland, M.R., and Vinson, J., 1990, Flow and transport at the Las Cruces trench site, experiments 1 and 2: U.S. Nuclear Regulatory Commission report NUREG/CR-5607, 413 p.

Wierenga, P.J., and Patterson, T.C., 1974, Quality of irrigation return flow in the Mesilla Valley, *in* Yegorov, V.V., Minashina, N.G., Skrynnikova, I.N., and Zaydel'man, F.R., eds., Reclamation of saline, waterlogged and bog soils; the changes in the soils under the impact of reclamation: International Congress of Soil Science, Transactions, no. 10, v. 10, Commission 6, p. 216-222.

Wiley, M.A., and Muehlberger, W.R., 1971, The Texas Lineament, *in* The geologic framework of the Chihuahua tectonic belt: West Texas Geological Society Publication No. 71-59, p. 15-23.

Willard, M.E., Weber, R.H., and Kuellmer, F.J., 1961, Reconnaissance geologic map of Alum Mountain 30-minute quadrangle: New Mexico Bureau of Mines and Mineral Resources Geologic Map 13, scale 1:126,720.

Williams, F.E., 1966, Fluorspar deposits of New Mexico: U.S. Bureau of Mines Information Circular 8307, 143 p.

Williams, F.E., Fillo, P.V., and Bloom, P.A., 1964, Barite deposits of New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 76, 46 p.

Williams, S.A., 1978, Mineralization at Granite Gap, Hidalgo County, New Mexico; *in* Callender, J.F., Wilt, J.C., Clemons, R.E., and James, H.L., eds., Land of Cochise, southeastern Arizona: New Mexico Geological Society, 29th Annual Field Conference, Guidebook, p. 329-330.

Willingham, D.L., 1979, Stratigraphy of the Pliocene-Pleistocene upper Santa Fe Group in the El Paso region, west Texas and south-central New Mexico [abs.]: Geological Society of America Abstracts with Programs, v. 11, no. 6, p. 305.

Wilpolt, R.H., Bates, R.L., McAlpin, A.J., and Vorbe, George, 1946, Geologic map and stratigraphic sections of Paleozoic rocks of Joyita Hills, Los Pinos Mountains, and northern Chupadera Mesa, Valencia, Torrance, and Socorro Counties, New Mexico: U.S. Geological Survey Oil and Gas Investigations Maps OM–61.

Wilpolt, R.H., and Wanek, A.A., 1951, Geology of the region from Socorro and San Antonio east to Chupadera Mesa, Socorro County, New Mexico: U.S. Geological Survey Oil and Gas Investigations Map OM-121, 2 sheets.

Wilson, C.A., White, R.R., Orr, B.R., and Roybal, R.G., 1981a, Water resources of the Rincon and Mesilla valleys and adjacent areas, New Mexico: U.S. Geological Survey Open-File Report 81-0487, 447 p.

Wilson, D.A., 1991, Depositional environments, provenance, and age of the Skunk Ranch Formation, Little Hatchet Mountains, southwestern New Mexico: Las Cruces, New Mexico State University, unpublished Master's thesis, 70 p.

Wilson, D.A., White, R.R., Orr, B.R., and Roybal, R.G., 1981b, Water resources of the Rincon and Mesilla valleys and adjacent areas, New Mexico: New Mexico State Engineer Technical Report 43, 514 p.

Wilson, E.D., 1937, Arizona goldplacers and placering: Arizona Bureau of Mines Bulletin 148, 54 p.

Wilson, G.C., 1986, Structural geology of the southern part of the northern Animas Mountains, south-central Hidalgo County, New Mexico: Las Cruces, New Mexico State University, unpublished Master's thesis, 115 p.

Wilson, J.L., 1989, Lower and Middle Pennsylvanian strata in the Orogrande and Pedregosa Basins, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 124, 16 p.

Wilson, M., McLemore, V.T., and Gundiler, I., 1993, Geology and ore-mineralogy of the Center mine, Steeple Rock mining district, New Mexico: A process mineralogy perspective: New Mexico Bureau of Mines and Mineral Resources Open File Report, 26 p.

Winchester, D.E., 1920, Geology of Alamosa Creek Valley, Socorro County, New Mexico, with special reference to the occurrence of oil and gas: U.S. Geological Survey Bulletin 716–A, p. 1–15.

Wisser, Edward, 1960, Relation of ore deposition to doming in the North American Cordillera: Geological Society of America Memoir 77, 117 p.

Witcher, J.C., 1979, A geothermal reconnaissance study of the San Francisco River between Clifton, Arizona and Pleasanton, New Mexico: Report Number Geothermal reservoir site evaluation in Arizona--Progress Report Department of Energy DOE/ID/12009-TI.

Witcher, J.C., 1988, Geothermal resources of southwestern New Mexico and southeastern Arizona, *in* Mack, G.H., Lawton, T.F., and Lucas, S.G., eds., Cretaceous and Laramide tectonic evolution of southwestern New Mexico: New Mexico Geological Society, 39th Annual Field Conference, Guidebook, p. 191-197.

Witcher, J.C., 1992, A geologic framework for geothermal systems in the southern Basin and Range province and the southern Rio Grande Rift, New Mexico [abs.]: New Mexico Geological Society Proceedings Volume, 1992 Annual Spring Meeting, p. 17. [Also New Mexico Geology, v. 14, no. 3, p. 62.]

Wood, B.J., and Virgo, D., 1987, Oxidation state of the upper mantle; ferric-ferrous ratios in coexisting minerals from spinel lherzolites [abs.]: Geological Society of America Abstracts with Programs, v. 19, no. 7, p. 896.

Wood, G.H., and Bour, W.V., III, 1991, Coal map, United States, Canada, and northern Mexico: U.S. Geological Survey, 2 sheets, scale 1:5,000,000.
Wood, G.H., and Northrop, S.A., 1950, South Canyon Creek dolomite member, a unit of Phosphoria age in Maroon formation near Glenwood Springs, Colorado: American Association of Petroleum Geologists Bulletin, v. 34, no. 7, p. 1540–1551.
Woodward, L.A., 1969, Comparative tectonics in petroleum exploration: Oil and Gas Journal, v. 67, April 26, p. 106-111.
Woodward, L.A., ed., 1970a, Guidebook of the Tyrone-Big Hatchet Mountains-Florida Mountains Region: New Mexico Geological Society, 21st Annual Field Conference, 162 p.
Woodward, L.A., 1970b, Precambrian rocks of southwestern New Mexico, *in* Woodward, L.A., ed., Guidebook of the Tyrone-Big Hatchet Mountains-Florida Mountains Region: New Mexico Geological Society, 21st Annual Field Conference, p. 27-31.
Woodward, L.A., 1978, A hard look at overthrust belt prospects in southwest New Mexico: Oil and Gas Journal, v. 78, no. 16, p. 114-116.
Woodward, L.A., Callender, J.F., Gries, J., Seager, W.R., Chapin, C.E., Shaffer, W.L., and Zilinski, R.E., 1975, Tectonic map of the Rio Grande region, Colorado-New Mexico border to Presidio, Texas, *in* Seager, W.R., Clemons, R.E., and Callender, J.F., eds., Guidebook of the Las Cruces Country: New Mexico Geological Society, 26th Annual Field Conference, Rio Grande Tectonic Map (in pocket), scale approximately 1:1,000,000.
Woodward, L.A., Callender, J.F., Seager, W.R., Chapin, C.E., Gries, J.C., Shaffer, W.L., and Zilinski, R.E., 1978, Sheet 2--Tectonic map of Rio Grande rift region in New Mexico, Chihuahua, and Texas, *in* Hawley, J.W., compiler, Guidebook to Rio Grande rift in New Mexico and Colorado: New Mexico Bureau of Mines and Mineral Resources Circular 163, scale 1,000,000.
Woodward, L.A., Callender, J.F., and Zilinski, R.E., 1975, Tectonic map of the Rio Grande rift, New Mexico: Geological Society of America map and chart series MC-11, scale 1:500,000.
Woodward, L.A., and Duchene, H.R., 1981, Overthrust belt of southwestern New Mexico--Comparison with Wyoming-Utah overthrust belt: American Association of Petroleum Geologists Bulletin, v. 65, no. 4, p. 722-727.
Woodward, L.A., and DuChene, H.R., 1982, Tectonics and hydrocarbon potential of thrust and fold belt of southwestern New Mexico, *in* Geologic studies of the Cordilleran Thrust Belt: Rocky Mountain Association of Geologists, v. 1, p. 409-419.
Wright, R.J., 1947, Dike and sill alteration, Santa Rita, New Mexico: New York, Columbia University, unpublished Ph. D. dissertation, unknown p.
Wrucke, C.T., and Bromfield, C.S., 1961, Reconnaissance geologic map of part of the southern Peloncillo Mountains, Hidalgo County, New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map MF-160.
Wrucke, C.T., Marsh, S.P., Conway, C.M., Kulik, D.M., Moss, C.K., Raines, G.I., and Ellis, C.E., 1983 [1984], Mineral resource potential map of the Mazatzal Wilderness and contiguous roadless area, Gila, Maricopa, and Yavapai Counties, Arizona: U.S. Geological Survey Miscellaneous Field Studies Map MF–1573–A, 15 p.
Wrucke, C.T., Werschky, R.S., Bankey, V.L., Kleinkopf, M.D., Staatz, M.H., Armstrong, A.K., McColly, R.A., and Scott, D.C., 1983 [1984], Mineral resource potential map of the Whetstone Roadless Area, Cochise and Pima Counties, Arizona: U.S. Geological Survey Miscellaneous Field Studies Map 1614–A, 10 p.
Wunder, R.D. and Trujillo, A.D., 1987, Chino mine modernization: Mining Engineering, v. 39, no. 7, p. 867-872.

Wurstner, S.K., Smyth, J.D., and Sagar, B., 1990, Comparison of results from a stochastic flow and transport model to field measurement at Las Cruces, New Mexico [abs.]: Geological Society of America Abstracts with Programs, v. 22, no. 7, p. 54.

Wynn, J.C., 1981a, Complete Bouguer gravity anomaly map of the Silver City 1°x2° quadrangle: U.S. Geological Survey Miscellaneous Investigation Series Map I-1310-A, scale 1:250,000.

Wynn, J.C., 1981b, Principal facts for gravity stations and base-station net in the Silver City 1°x2° quadrangle, Arizona and New Mexico: U.S. Geological Survey Open-File Report 81-0040, 141 p.

Wynn, J.C., Waitzeneger, B., Watters, T.R., Mirzai, P.H., and Gardner, A., 1983, Aeromagnetic map and magnetic source analysis map of the San Simon 15-minute quadrangle, Arizona and New Mexico: U.S. Geological Survey Open-File Report 83-0631.

Yanicak, S.M., Seager, W.R., Giordano, T.H., and McCurry, M.O., 1992, Petrology of silicic and syenitic facies of the Organ Needle pluton, Organ Mountains batholith, Doña Ana County, southern New Mexico [abs.]: New Mexico Geological Society Proceedings Volume, 1992 Annual Spring Meeting, p. 21. [also New Mexico Geology, v. 14, no. 3, p. 63-64.]

Yates, J.C., 1961, Changes in quantity of ground water, *in* Stucky, H.R., ed., Proceedings of the Annual New Mexico Water Conference, v. 6, p. 23-30.

Young, L. M., 1982, Fluid-inclusion temperatures of diagenesis in the Lake Valley Formation (Mississippian) near Silver City, New Mexico: Geological Society of America 95th annual meeting, Abstracts with Programs, v. 14, no. 7, p. 651.

Young, L.M., 1994, Paleokarst, paleosols, cave fillings, and breccias at the Fusselman Dolomite-Percha Shale unconformity, Silver City area, New Mexico: New Mexico Geology, v. 16, no. 1, p.7-13.

Young, T.H., 1982, Geological and exploration characteristics of precious-metal mineralization at the Volcano mine and vicinity, Peloncillo Mountains, Hidalgo County, New Mexico: Tucson, University of Arizona, unpublished Ph. D. dissertation, unknown pages.

Yountz, R.B., 1931, Mining methods at the Eighty-Five mine, Calumet and Arizona Mining Co., Valedon, N. Mex.: U.S. Bureau of Mines Information Circular 6413, 26 p.

Yousefpour, M.V., 1978, Geology and contact pyrometasomatic ore deposits at the Continental Mine, Fierro, New Mexico: Golden, Colorado School of Mines, unpublished Master's thesis, unknown p.

Yousefpour, M.V., 1980, Genesis of skarn polymetallic deposits in the Hanover-Fierro area and a geotechnical evaluation of pit slope stability at the Continental Mine, Fierro, New Mexico: Golden, Colorado School of Mines, unpublished Ph. D. dissertation, unknown p.

Yurewicz, D.A., 1973, Genesis of the Rancheria and Las Cruces(?) Formations (Mississippian) of south-central New Mexico and west Texas: Madison, University of Wisconsin, unpublished Master's thesis, 249 p.

Yurewicz, D.A., 1977, Sedimentology of Mississippian basin-facies carbonates, New Mexico and West Texas--The Rancheria Formation: Society of Economic Paleontologists and Mineralogists, Special Publication 25, p. 203-219.

Zalinski,, E.R., 1907, Turquoise in the Burro Mountians, New Mexico: Economic Geology, v. 2, no. 5, p. 464-492.

Zamzow, M.J., Eichbaum, B.R., Sandgren, K.R., and Shanks, D.E., 1990, Removal of heavy metals and other cations from wastewater using zeolites: Separation Science and Technology, v. 25, p. 1555-1569.

Zeller, R.A., 1958a, Geology of Little Hatchet Mountains, Hidalgo and Grant Counties, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 96, 22 p.

Zeller, R.A., Jr., 1958b, The geology of the Big Hatchet Peak quadrangle, Hidalgo County, New Mexico: University of California, Los Angeles, unpublished Ph. D. dissertation, 260 p.
Zeller, R.A., 1958c, Reconnaissance geologic map of Dog Mountains quadrangle: New Mexico Bureau of Mines and Mineral Resources Geologic Map 8, scale 1:62,500.
Zeller, R.A., 1959, Reconnaissance geologic map of Playas 15' quadrangle: New Mexico Bureau of Mines and Mineral Resources Geologic Map 7, scale 1:62,500.
Zeller, R.A., Jr., 1960, Reef and associated facies of Horquilla Limestone, Big Hatchet Mountains area, southwestern New Mexico: Roswell Geological Society Guidebook, Northern Franklin Mountains and southern San Andres Mountains, p. 149-156.
Zeller, R.A., 1962, Reconnaissance geologic map of southern Animas Mountains: New Mexico Bureau of Mines and Mineral Resources Geologic Map 17, scale 1:62,500.
Zeller, R.A., 1965, Stratigraphy of the Big Hatchet Mountains area, New Mexico: New Mexico Bureau of Mines and Mineral Resources Memoir 16, 128 p.
Zeller, R.A., 1970, Geology of the Little Hatchet Mountains, Hidalgo and Grant Counties, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 96, 23 p.
Zeller, R.A., Jr., *with commentary by* Sam Thompson, III, 1975, Structural geology of Big Hatchet Peak quadrangle, Hidalgo County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 146, 23 p., scale 1:48,000.
Zeller, R.A., and Alper, A.M., 1965, Geology of the Walnut Wells quadrangle, Hidalgo County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 84, 105 p., scale 1:48,000.
Zohdy, A.A., Eaton, G.P., Mabey, D.R., 1974, Application of surface geophysics to ground-water investigations, U.S. Geological Survey, Techniques of Water-Resources Investigations of the United States Geological Survey: Washington D.C., U.S. Government Printing Office, publication TWI02-D1 (reprinted 1990), 116 p.

APPENDIX B

STRATIGRAPHIC NAMES USED IN
GEOLOGY of the MIMBRES RESOURCE AREA
Compiled by Susan Bartsch–Winkler
from
Stratigraphic Nomenclature Databases
for the United States, It's Possessions, and Territories,
U. S. Geological Survey DDS–6, Release 2, 1994
and referenced sources

Abo Formation (basal formation of Manzano Group (Lee, 1909)(see also Hueco Group); Wilpolt and others, 1946; Kelley and Wood, 1946; Wood and Northrop, 1946; Kelley and Silver, 1952; Bachman and Hayes, 1958; Kottlowski, 1963, 1965; Jordan, 1975; Mack and James, 1986; Kottlowski and LeMone, 1994)

Age: Early Permian (Wolfcampian, Leonardian)

Occurrence/unit thickness: Big Hatchet Mountains (134 m thick); Black Range (122 m thick); Cookes Range(Fluorite Ridge), 46 m thick; Cobre Uplift (0-61 m thick); Pinos Altos Range/Silver City Range (0-81 m thick); San Diego Mt/Tonuco Uplift. In the Florida Mountains, a unit that may be correlative to the Abo, is 31-153 m thick. In the San Andres Mountains, Abo sediments are finer grained than typical red beds to the north; grades southward into marine Hueco Group (Bachman and Myers, 1969). Abo is 255 m thick at Love Ranch. Abo is probably not present south of the Robledo Mountains, where a tongue of Abo is present within the Hueco Group. Abo Formation and Hueco Group are undifferentiated in the Doña Ana Mountains, where they are reported to be 458 m thick (122 m of Abo; at least 204 m of Hueco); base and top not exposed. Isopachs of the Abo, Earp, and Hueco-Horquilla facies in southern N. Mex., the Mesozoic eroded edge, and the Burro Uplift, are given in Kottlowski (1963, fig. 9).

Type locality: none; named for Abo Canyon, southern end of Manzano Range, sec. 29, T. 3 N., R. 6 E., Torrance County (Lee, 1909)

Correlation/subunits: Abo and Hueco intertongue in the southern San Andres and Organ Mountains.

Lithologies: Interbedded limestone, limestone-chert conglomerate, reddish siltstone, shale, and sandstone;

Fossils: In the Robledo Mountains, exposure of a dinosaur tracksite, mudcracks, root tubes, and raindrop imprints (attributed to Abo–Hueco deposits)

Depositional environment: Orogrande basin facies rocks in Doña Ana Mountains; nonmarine terrestrial) siliciclastics. Marks the shoreline with the Hueco marine beds.

Stratigraphic relations to underlying units or predecessors: Bursum(?) age rocks beneath the Hueco in the Doña Ana Mountains.

Stratigraphic relations to overlying units or successive rocks: In the Silver City/Pinos Altos area, the Abo is unconformably overlain by Late(?) Cretaceous Beartooth Quartzite (Cenomanian, possibly as old as Albian; Molenaar, 1983) and younger rocks. In the Cookes Range, it is overlain by Early Cretaceous Sarten Sandstone. Palm Park strata overlie the Abo-Hueco sequence in the Doña Ana Mountains.

Commodities: Zn-Pb skarn deposits adjacent to stock at Shingle Canyon mines (Hanover Fierro stock). Porphyry-copper-associated copper-sulfide deposits, Santa Rita district. Gypsum occurrences locally.

Afton Basalt, Aden Basalt (Potrillo Basalt) (El Paso Geological Society, 1973; Hoffer, 1976)
Age: Quaternary, younger than middle Pleistocene; may be only a few thousand years old
Occurrence/thickness: Potrillo Mountains
Type locality: none. First used by El Paso Geological Society, 1973. Isotopic dating in Hoffer, 1976
Correlation:
Lithologies: basalt; may be olivine–rich
Fossils:
Depositional environment: Basalt flow.
Stratigraphic relations to underlying units or predecessors: La Mesa Bolson fill and possibly Permian and Cretaceous carbonate and clastic rocks
Stratigraphic relations to overlying units or successive rocks: Maar material including tuff, scoriaceous bombs, olivine-cored bombs, pumice, ash.
Commodities: Scoria, pumice, lava rock, peridot (gemstone), perlite, guano (Aden Crater area)

Aleman Dolomite (Montoya Group)(Kelley and Silver, 1952; Zeller, 1965; Thorman and Drewes, 1980, 1991)
Age: Late Ordovician
Occurrence: Big Hatchet Mountains (23 m thick); Bishop Cap (60 m thick); Florida Mountains; Pinos Altos/Silver City Range (18 m); Robledo Mountains (27 m thick); southern San Andres Mountains (46-52 m thick), thins northward; Victorio Mountains
Type locality: Oppposite the Sierrite Mine at head of Cable Canyon, NW 1/4 sec. 10, T. 16 S., R. 4 W., Caballo Mountains, Sierra Co. (Kelley and Silver, 1952)
Correlation:
Lithologies: Finely crystalline, thin- to massive-bedded dolomite and limestone with distinctive bands, lenses, and nodules of chert. In the Organ Mountains, upper part may be chert-free.
Fossils: Brachiopods, corals, and bryozoa; locally silicified.
Depositional environment: marine
Stratigraphic relations to underlying units or predecessors:
Stratigraphic relations to overlying units or successive rocks: In the Organ Mountains, grades into the overlying Cutter Dolomite.
Commodities: Silver deposits in Lone Mountain district

Alum Mountain, volcanic complex of (Elston, 1968; Ratté and others, 1972, 1979)
Age: Tertiary, Oligocene; 29+1.0 (Ratté and others, 1972)
Occurrence/thickness: Alum Mountain, Mogollon Mountains
Type locality: none; named for Alum Mountain, Grant Co.
Correlation: Largely equivalent to the Alum Mountain Formation
Lithologies: Latite to basaltic andesite
Fossils: n.a.
Depositional environment: Flows, breccias, pyroclastic and volcanic rocks, associated small intrusive bodies
Stratigraphic relations to underlying units or predecessors:
Stratigraphic relations to overlying units or successive rocks: According to Ratté and others (1972), the volcanic complex of Alum Mountain is a basal unit overlain unconformably by latitic and andesitic flows of Gila Flat, which surround the complex.
Commodities: includes hydrothermally altered rocks in Copperas Creek and Alum Mountain areas (Alum Mountain district)

Alum Mountain Formation (Elston, 1968; Ratté and others, 1972; 1979)
Age: Tertiary, Oligocene
Occurrence/unit thickness: Alum Mountain and Copperas Mountain area, Gila Canyon, Pinos Altos Mountains, west flank of the Black Range; Gila Primtive Area and Gila Wilderness (0-427 m+ ft thick), Mogollon Mountains
Type locality: none. Named for Alum Mountain, Grant Co. (Elston, 1968)
Correlation: May correlate with the Razorback Formation and Bear Springs Basalt (Mimbres Valley); correlates with the andesite of Aspen Canyon (Ericksen and others, 1970); largely equivalent to part of the Alum Mountain Formation (Ratté and others, 1979)
Lithologies: Latite to basaltic andesite flows
Fossils: n.a.
Depositional environment: pre-caldera rocks of the Gila Cliff Dwellings and Bursum calderas
Stratigraphic relations to underlying units or predecessors: Overlies Tadpole Ridge Formation; intertongues with upper part of Tadpole Ridge Formation
Stratigraphic relations to overlying units or successive rocks: Underlies the Bloodgood Canyon Tuff
Commodities:

Anapra Formation (Strain, 1976; Lovejoy, 1976; Cornell and LeMone, 1987)
Age: Early Cretaceous, Comanchean
Occurrence/unit thickness: Cerro de Cristo Rey (210 ft thick)
Type locality: on east side of road to Cerro de Cristo Rey in SW1/4 SE1/4 sec 9, T 29 S., R. 4 E., Dona Ana Co; named for small community in Dona Ana County (Strain, 1976)
Correlation:
Lithologies: Quartzose sandstone and siltstone, arkosic sandstone, bluish shaly siltstone
Fossils:
Depositional environment:
Stratigraphic relations to underlying units or predecessors: Mesilla Valley Formation
Stratigraphic relations to overlying units or successive rocks: Del Rio Formation
Commodities: Bluish to purplish shaly siltstone is quarried for brick-making. Silica-rich layers mined for smelter flux.

Antelope Pass unit (Elston, 1983, 1984)
Age: Tertiary
Occurrence/unit thickness: Peloncillo (Rodeo caldera)
Type locality: none. In Peloncillo Mountains, this unit is used to determine the existence of Rodeo caldera (Elston, 1983, 1984)
Correlation:
Lithologies: megabreccia
Fossils:
Depositional environment: volcanic deposits that determine the existence of Rodeo caldera
Stratigraphic relations to underlying units or predecessors:
Stratigraphic relations to overlying units or successive rocks:
Commodities:

Apache Box rhyolite (Hedlund, 1990, Ratté and Hedlund, 1981)
Age:
Occurrence/thickness: north of Steeple Rock district

Type locality:
Correlation:
Lithology: rhyolite
Fossils:
Depositional environment: plugs and dikes
Stratigraphic relations to underlying rocks or predecessor(s): intrude the Dark Thunder Canyon formation and lava flows of Crookson Peak
Stratigraphic relations to overlying rocks or successor(s):
Commodities:

Apache Hills quartz monzonite (Strongin, 1958;)
Age:
Occurrence/unit thickness: Sierra Rica and Apache Hills
Type locality: Apache Hills stock, Apache Hills
Correlation:
Lithologies: quartz monzonite
Fossils: n.a.
Depositional environment: resurgent part of Apache Hills caldera
Stratigraphic relations to underlying units or predecessors:
Stratigraphic relations to overlying units or successive rocks:
Commodities:

Apache Spring Tuff (Elston, 1968; Rhodes and Smith, 1976; Ratté, 1981; Marvin and others, 1987)
Age: Tertiary, Oligocene
Occurrence/unit thickness: Mogollon Mountains
Type locality: Center of sec. 36, T. 11 S., R. 18 W., named for Apache Spring, Grouse Mountain quadrangle, Catron Co. (Ratté, 1981)
Correlation:
Lithologies: Quartz latite
Fossils:
Depositional environment:
Stratigraphic relations to underlying units or predecessors:
Stratigraphic relations to overlying units or successive rocks:
Commodities:

Ash Creek Group (Hewitt, 1959; Wargo, 1959; Elston, 1960; Gillerman, 1970)
Age: Precambrian, Early Proterozoic
Occurrence/unit thickness: Big Burro Mountains
Type locality: none; named for Ash Creek south of Mingus Mountain, Yavapai Co., Az. (Anderson and Creasey, 1958)
Correlation:
Lithologies: metamorphic rocks
Fossils:
Depositional environment: Formed by regional greenschist metamorphism and contact metamorphism of sedimentary rocks
Stratigraphic relations to underlying units or predecessors: Bullard Peak series are older metamorphic rocks
Stratigraphic relations to overlying units or successive rocks:

Commodities: Ricolite, Ricolite mining district.

Bat Cave Member (Montoya Group)(Kelley and Silver, 1952; Zeller, 1965; Maxwell and Oakman, 1990)
Age: Ordovician
Occurrence/unit thickness:
Type locality: North side of Cable Canyon. Named from Bat Cave, whose opening is a prominent landscape mark oon the sheer cliff in the upper part of the Formation just northwest of the type section E 1/2, sec. 10, T. 16 S. R. 4 W., Sierra County NM
Correlation: Not used in Big Hatchet Mountains (Drewes, 1991a)
Lithologies:
Fossils:
Depositional environment
Stratigraphic relations to underlying units or predecessors:
Stratigraphic relations to overlying units or successive rocks:
Commodities: Manganese deposits, Rincon district

Bear Creek basalt (Reiter, 1980)
Age: Tertiary
Occurrence/unit thickness: Alamo Hueco Mountains (up to 9 m thick)
Type locality: none; south bank of Bear Creek, Alamo Hueco Mountains
Correlation: basalt of San Luis Mountains of Erb (1979)
Lithologies: alkali basalt, vesicular.
Fossils: n.a.
Depositional environment
Stratigraphic relations to underlying units or predecessors: conformable on Park tuff
Stratigraphic relations to overlying units or successive rocks:
Commodities:

Bear Springs Basalt (Jicha, 1954; Elston, 1954, 1957)
Age: late Tertiary (26.6-29.8 m.y.; Clemons, 1979)
Occurrence/unit thickness: Black Range (305 m thick), Lake Valley and Mimbres Valley, Cobre Mountains.
Type locality: none; stated to be in sec. 25, T. 18 S., R. 9 W., Lake Valley quadrangle, Sierra Co (attributed to Jicha, 1954, *in* Elston, 1954)
Correlation: Miocene(?) basaltic andesite of Jones and others (1967), Pinos Altos Range/Silver City Range. Possibly correlative with the Oligocene–early Miocene Uvas Andesite (Gates, 1985). Potentially correlative units in the Carrizalillo Hills.
Lithologies: Basaltic andesite, basalt.
Fossils: n.a.
Depositional environment: Volcanic flow
Stratigraphic relations to underlying units or predecessors: Razorback Formation
Stratigraphic relations to overlying units or successive rocks: Swartz Rhyolite
Commodities:

Beartooth Quartzite (Paige,1916; Kottlowski, 1963; Hayes, 1970; Cunningham, 1974; Hedlund, 1978; Morrison, 1965)
Age: Late? Cretaceous

Occurrence/unit thickness: Pinos Altos Range/Silver City Range (15-47 m thick); Burro Mountains. Partly stoped and domed by the Hanover-Fierro pluton. In contact with the Santa Rita stock. Steeple Rock area. Soldiers Farewell Hill quad, questioned occurrence. MIneralized in the Telegraph mine, Telegraph mining district.

Type locality: None. Section measured in smal canyon 1.5 km north–northwest of Silver City, Silver City quadrangle, Grant Co. Named for Beartooth Creek near Fort Bayard (Paige, 1916).

Correlation: Possibly with Sarten Sandstone, but probably slightly younger. Molenaar (1990) states that the Beartooth is probably coeval to or slightly older than the Dakota in south-central New Mexico.

Lithologies: Orthoquartzite, sandstone, minor black shale, conglomerate. Clasts are quartzose (jasperoid or chert)

Fossils: Trace fossils; wood fragments; crinoid fragments. None diagnostic of age.

Depositional environment: deltaic. Sources for the Beartooth and Dakota sandstones may have been partly derived locally, but paleocurrent analysis suggests a source terrane to the west-southwest.

Stratigraphic relations to underlying units or predecessors: Unconformable on Abo, on weathered Precambrian granite

Stratigraphic relations to overlying units or successive rocks: conformable with Colorado Formation

Commodities: Silica flux; mineralized in Slate Creek Canyon, Telegraph district; mineralized at Fleming Camp mine, Fleming district. Skarn deposits (copper) in Piños Altos district. Porphyry-copper-associated copper-sulfide deposits, Santa Rita district. Uranium mineralization at unconformity with Precambrian graine and within fault zones.

Bell Top Formation (Kottlowski, 1953; Clemons and Seager, 1973; Seager, 1973; Seager, Clemons, and Hawley, 1975; Clemons, 1975; Seager and Clemons, 1975)

Age: Tertiary, Oligocene [K-Ar dating on several members indicate an early to middle Oligocene age; 33–39.4 m.y. (Clemons, 1975; Seager and Clemons, 1975). Relative ages deciphered using intertonguing relations and radiometric dating methods.]

Occurrence/unit thickness: Thirteen informal members (Clemons, 1976) separated by unconformities. Units are nowhere present in their entireity. Distribution corresponds to the Cedar Hills-Good Sight Mountains depression. Central Sierra de las Uvas (as much as 458 m thick), Cedar Hills (over 488 m thick), San Diego Mountain [Tonuco Uplift and west Selden Hills (214 m thick)], Sleeping Lady Hills, Rough and Ready Hills. Lesser thicknesses occur in the Rincon Hills and Good Sight Mountains. Pinches out in northern West Potrillo Mountains. Occurs near the surface in the Jornada del Muerto.

Type locality: none

Correlation: Interfingers with lower part of the Thurman Formation in Rincon Hills. Probably correlates with the Sugarlump Formation of Mimbres Valley.

Lithologies: Thirteen informal members, composed of 6 ash-flow tuffs, Cedar Hills rhyolite, basaltic andesite, basalt, and four sedimentary units, including coarse-grained components. Ash-flow tuff units belong to a single cooling episode and are generally identified using variability in ratios between quartz-alkali feldspar and plagioclase. Rhyolite pebble breccia at San Diego Mountain.

Fossils:

Depositional environment: Primarily ejecta from Cedar Hills vent zone (Seager, 1973, 1975; Seager and Clemons, 1975)

Stratigraphic relations to underlying units or predecessors: Unconformable with Palm Park Formation, Rubio Peak Formation, Kneeling Nun Tuff
Stratigraphic relations to overlying units or successive rocks: Unconformable with Uvas Basaltic Andesite, Rincon Valley Formation, Camp Rice Formation. Overlain by andesite of Faulkner Canyon (Seager and Clemons, 1975) in Cedar Hills-Selden Hills area.
Commodities: Potential for pumice, clay, zeolites at Foster Canyon

Bennett Spring tuff (Deal and others, 1978)
Age: Oligocene
Occurrence/unit thickness: Animas Mountains
Type locality: none
Correlation:
Lithologies: Quartz latite
Fossils: n.a.
Depositional environment: Ash-flow tuff from 35 m.y.–old Juniper caldera, forming one deposit of the moat and ring–fracture system
Stratigraphic relations to underlying units or predecessors:
Stratigraphic relations to overlying units or successive rocks:
Commodities:

Berino Formation (Magdalena Group)(Nelson, 1940; Harbour, 1972; Seager, 1981)
Age: Middle Pennsylvanian; Atokan, Desmoinesian
Occurrence/unit thickness: Northern Franklin Mountains (as much as 162 m thick). Described from southern Organ Mountains. Forms Bishop Cap peak .
Type locality: none; named for town on the Santa Fe Railroad about 4 mi north of the TX–NM boundary, Dona Ana Co. (Nelson, 1940)
Correlation/subunits: First used as middle of three members of Magdalena Group in the Franklin Mountains (Nelson, 1940)
Lithologies: Shale, interbedded intraclastic and micritic limestone, locally cherty. Top is massive limestone, Franklin Mountains
Fossils: Mollusks, brachiopods, corals, bryozoa, algae, and fusulinids; petrified wood locally
Depositional environment: Nearshore marine
Stratigraphic relations to underlying units or predecessors: Conformably overlies La Tuna Formation
Stratigraphic relations to overlying units or successive rocks: Gradational into Bishop Cap, northern Franklin Mountains.
Commodities:

Bisbee Group (Dumble, 1902; Ransome, 1904; Stoyanow, 1937, 1949; Butler and others, 1937; Lasky, 1938; Gilluly, 1945, 1956; Cooper, 1950, 1959; Sabins, 1957; Gillerman, 1958; Cooper and Silver, 1964; Hayes and Landis, 1965; Hayes, Simons, and Raup, 1965; Creasey, 1967; Drewes, 1968, 1970, 1975, 1980, 1981, 1991; Hayes, 1970, 1982; Hayes and Raup, 1968; Finnell, 1970; Zeller, 1975; Armstrong and others, 1978; Drewes and Thorman, 1980; Keith and Barrett, 1976)
Age: Early Cretaceous
Occurrence/thickness: Big Hatchet Mountains; central Peloncillo Mountains; Sierra Rica and Apache Hills; Victorio Mountains; Tres Hermanas; Little Hatchet Mountains
Type locality: Bisbee beds named for Bisbee, Cochise Co., AZ (Dumble, 1902)
Correlation:

Subunit names: Cintura Formation, Mural Limestone, Glance Conglomerate. In the Little Hatchet Mountains, has been subdivided into Broken Jug limestone, Ringbone Formation, Hidalgo volcanics, Howells Ridge formation, Corbett sandstone, Playas Peak formation, and Skunk Ranch conglomerate. In the central Peloncillo Mountains, has been subdivided into McGhee Peak Formation, Carbonate Hill Limestone, and Johnny Bull Sandstone and Still Ridge Formation. In the Sierra Rica, is composed of the Glance Conglomerate, Mural Limestone, and Cintura Formation.
Lithology
Fossils:
Depositional environment:
Stratigraphic relation to underlying rocks:
Stratigraphic relations to overlying rocks:
Commodities:

Bishop Cap Formation (Magdalena Group) (Nelson, 1940; El Foul, 1976; Kelley and Matheny, 1983)
Age: Middle Pennsylvanian
Occurrence/thickness: Franklin Mountains, where it is mapped as an undifferentiated unit with the La Tuna and Berino Formations for a total thickness of 824 m
Type locality: none; named for Bishop's Cap Peak opposite Filmore, Dona Ana Co. Section was measured in the Franklin Mountains, Vinton, TX (Nelson, 1940). At this locality, as much as 194 m thick.
Correlation:
Lithologies: Shale with thin beds of limestone; small lenses and nodules of chert; chert replacement of fossils.
Fossils: Abundant; include algae, gastropods, pelecypods, corals, brachiopods, and fusulinids
Depositional environment:
Stratigraphic relations to underlying rocks or predecessors:
Stratigraphic relations to overlying rocks or successors:
Commodities: Northern Franklin Mountains District: Copiapo jarosite mine; replacement and vein deposits along fault containing jarosite, limonite hematite, gypsum, calcite, aragonite

Black Bill Canyon, tuff of (refs)
Age: Oligocene
Occurrence/thickness:
Type locality:
Correlation:
Lithologies: Rhyodacite to quartz latite
Fossils:
Depositional environment: Ash-flow tuff
Stratigraphic relations to underlying rocks or predecessors:
Stratigraphic relations to overlying rocks or successors:
Commodities:

Bliss Formation (Richardson, 1904; Paige, 1916; Kelley, 1951; Kottlowski and others, 1956; Kottlowski, 1963; Zeller, 1965; Bachman and Myers, 1969; Hayes, 1972, 1975; Armstrong and others, 1978; Jones and others, 1970; Hedlund, 1978, Gold Hill quad; Repetski, 1988; Evans and Clemons, 1988; Thorman and Drewes, 1981; Drewes, 1991)
Age: Late Cambrian (Dresbachian, Franconian, Trempealeauan), Early Ordovician

Occurrence/thickness: Animas Mountains (320 ft thick, but highly variable due to faulting), Big Hatchet Mountains (59-100 m thick), Black Mountains/Knight Peak area, Black Range (34-40 m thick), Cedar Mountains area (up to 7 m thick), Cobre Uplift (43-57 m thick), Cookes Range and Fluorite Ridge (29 m thick), Florida Mountains (0-60 m thick, variable owing to variable infilling over paleotopography), northern Franklin Mountains (up to 76 m thick), northern Organ Mountains and southern San Andres Mountains (about 44 m thick), Peloncillo Mountains (18-20 thick), Pinos Altos Range/Silver City Range (43-69 m thick), Robledo Mountains (subsurface), San Diego Mountain, Sierra Rica/Apache Hills, Tonuco Uplift (38 m thick), Victorio Mountains (subsurface), Klondike Hills, Victorio Mountains (subsurface). Pinches out in the Oscura Mountains. Occurs in small isolated hills in Hatchet Gap, southern Little Hatchet Mountains, where it rests unconformably on Precambrian granite (Zeller, 1970). Questionable Bliss is about 50 m thick in Gold Hill quad and Werney Hill quad (Hedlund, 1978)

Type locality: None. Name taken from Fort Bliss, which is situated on the mesa immediately east of the outcrop, in southern Franklin Mountains, El Paso Co. TX (Richardson, 1904)

Correlation: In the Peloncillo Mountains, Coronado Sandstone is described as an intermediate facies between the Bliss Sandstone and Bolsa Quartzite (in Arizona).

Lithologies: Characteristically dark-weathering quartzitic sandstone and arkose that is locally hematitic. Includes glauconitic shale and siltstone, and basal arkosic grit and conglomerate. Locally contains dolomite, oolitic hematite, pebbly siliceous hematitic sandstone, and lenses of siliceous hematite, arenaceous shale, and arenaceous limestone. Cements may be calcareous, hematitic, and siliceous.

Fossils: Sparse; an age has been assigned using fossils (gastropods, brachiopods, cephalopods, and trace fossils) in some locations. Late Cambrian trilobite fauna occurs in Tonuco Uplift, east of Santa Rita, and in the Black Mountains/Knight Peak area. Linguoid brachiopods occur in the rocks in the Black Mountains/Knight Peak area. Linguoid brachiopods and *Skolithos* tubes are present in the Sierra Rica. The Ordovician age is suggested to occur in the Franklin Mountains, the type locality of the Bliss and one of the thickest sequences (Flower, 1959).

Depositional environment: Transgressive coastal to shallow marine deposit (Seager, 1981). Abundant glauconite; manganese coatings on grains. Mostly tidal deposit with minor beach, fluvial, deltaic deposits. Stagemen (1987) interpreted the Bliss as a wave- and storm-dominated deposit. Represent initial transgressive deposits on the continental craton. Isopachs (Kottlowski, 1963) indicate thickening in southwestern Hidalgo County to as much as 600 ft, thinning in a southwest trending "ridge" through Luna County and northern Doña Ana County. The Bliss thins to the northeast to less than 31 m thick, but is as much as 76 m thick in the vicinity of El Paso.

Stratigraphic relations to underlying units or predecessors: Everywhere unconformable, or nearly conformable, on Precambrian and Cambrian basement granitic and metamorphic rocks. Fills depressions on Precambrian erosion surfaces, except in the Florida Mountains where it rests unconformably on diamictite and alkalic igneous rocks of probable Cambrian to Ordovician age.

Stratigraphic relations to overlying units or successive rocks: May be juxtaposed to both older and younger units by faulting. In the Pinos Altos Range/Silver City Range, contact with the El Paso is obscure, and occurs locally adjacent to the Hanover-Fierro pluton. In southwestern New Mexico, the Bliss is conformably and gradationally overlain by El Paso.

Commodities: San Andrecito-Hembrillo District: vein- and replacement-deposits along faults at Green Crawford Mine; hematite. Oolitic ironstone (iron), Fleming district; Piños Altos district. Disseminated oolitic hematite, San Andres Mountains.

Bloodgood Canyon Tuff (Elston, 1968; Lawrence, 1986; Lawrence and Richter, 1986; Ratté, 1981; Ratté and others, 1984; Hedlund, 1993)
Age: Tertiary, Oligocene; 28.1 m.y. (McIntosh and others, 1991)
Occurrence/unit thickness: Northwestern Pinos Altos Mountains, Silver City Range, northern Big Burro Mountains; Gila Primitive Area and Gila Wilderness (at least 305 m thick, possibly 610 m thick within the Gila Cliff Dwellings caldera); maximum 88 m thick in Tillie Hall Peak quad (Hedlund, 1993), Mogollon Mountains, Summit and Big Lue Mountains. Extends from the Bursum caldera northward to Aragon, and as far south as a few km south of Steeple Rock, as far west as Clifton, and as far east as Beaverhead (McIntosh and others, 1990 a,b.)
Type locality: Secs 5,6, T. 13 S., R. 14 W.; named for Bloodgood Canyon, Little Turkey quad, Catron County (Elston, 1968)
Correlation: Tuff of Apache Spring; Noah Mesa Tuff of Wahl, 1980 (unpublished M.S. thesis)
Lithologies: high-silica rhyolite
Fossils:
Depositional environment: Major rhyolite ash-flow tuff sheet. Episode 3 ignimbrite, Mogollon-Datil volcanic field. Source in the Bursum caldera (Ratté and others, 1984). 14,996 km^2 in extent. It may have initiated the collapse of the Bursum caldera, and probably comprises the pre-caldera rocks of the Gila Cliff Dwellings and Bursum calderas. Thickness and distribution of this unit provides evidence for the existence of the Gila Cliff Dwellings caldera.
Stratigraphic relations to underlying units or predecessors: Unconformably overlies pre-caldera rocks. Alum Mountain Formation; uncertain relation with Apache Spring Quartz latite
Stratigraphic relations to overlying units or successive rocks: uncertain
Commodities:

Bluff Creek Formation (Zeller and Alper, 1965)
Age: Tertiary, Oligocene; 36.5+1.8; fission track; Deal and others, 1978; Erb, 1979
Occurrence/unit thickness: Animas Mountains; Alamo-Hueco-Dog Mountains; Big Hatchet Mountains
Type locality: None. Named for Bluff Creek, eastern Animas Mountains, south–central part of Walnut Wells quad, S1/2, T 31 S., R. 17 W., Hidalgo County. Volcanic rocks are derived from Animas Mountains (Zeller and Alper, 1965)
Correlation:
Lithologies: Rhyolite
Fossils: n.a.
Depositional environment: Ash-flow and air-fall tuffs; sedimentary rocks; fill of Tullous caldera (Erb, 1979)
Stratigraphic relations to underlying units or predecessors:
Stratigraphic relations to overlying units or successive rocks:
Commodities: travertine and manganese (Alamo Hueco and Dog Mountains; Reiter, 1980)

Boquillas Formation (Böse, 1910, Strain,1968; Lovejoy, 1976; Barnes, 1977; Uphoff, 1978)
Age: Late Cretaceous; Cenomanian to Turonian (biostratigraphic dating with ammonites in TX; Cobban, 1988)
Occurrence/unit thickness: Cerro de Cristo Rey (110 m thick)

Type locality: none; in vicinity of Boquillas Post Office along the west flank of the Carmen Range, southeast Brewster Co. TX (Udden, 1907)
Correlation:
Lithologies: calcareous shale, thin-bedded limestone, shale. Locally intruded by andesite sills.
Fossils: unfossiliferous shale
Depositional environment:
Stratigraphic relations to underlying units or predecessors: Buda Formation
Stratigraphic relations to overlying units or successive rocks: Fort Hancock Formation
Commodities:

Brick Plant Member (lower clay member, Del Norte Formation (Strain, 1968; Lovejoy, 1976)
Age: Early Cretaceous
Occurrence/unit thickness: Cerro de Cristo Rey
Type locality:
Correlation:
Lithologies:
Fossils:
Depositional environment:
Stratigraphic relations to underlying units or predecessors:
Stratigraphic relations to overlying units or successive rocks:
Commodities:

Brick Plant Member (lower clay member, Del Norte Formation (Strain, 1968; Lovejoy, 1976)
Age: Early Cretaceous
Occurrence/unit thickness: Cerro de Cristo Rey
Type locality:
Correlation:
Lithologies:
Fossils:
Depositional environment:
Stratigraphic relations to underlying units or predecessors:
Stratigraphic relations to overlying units or successive rocks:
Commodities:

Brock Canyon volcanic complex (informal name)
Age: 30-33 Ma (Ratté and others, 1979)
Occurrence/thickness: at least 304 m thick (Ratté and others, 1979)
Type locality: none. Located in the Gila Flurospar District, Grant County
Correlation:
Lithology: altered and unaltered latitic lava flows, volcanic breccia, and possible intrusives
Fossils:
Depositional environment:
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s): silicic ash-flow tuffs and Gila Conglomerate
Commodities: fissure veins with fluorite at Clum mine, Gila Flurospar district, Grant County

Brushy Mountain andesitic lava

Age: 22-25 m.y. (Ratté and Hedlune, 1981; Ratté and Brooks, 1983)
Occurrence/thickness: Steeple Rock, Hells Hole area
Type locality:
Correlation:
Lithology: andesite
Fossils:
Depositional environment: lava flow
Stratigraphic relations to underlying rocks or predecessor(s): lavas of Maverick Hill and Mullen Peak
Stratigraphic relations to overlying rocks or successor(s):
Commodities:

Buda Limestone (Hill, 1901; Lovejoy, 1976; Uphoff, 1978)
Age: Late Cretaceous, Cenomanian; Washita Group
Occurrence/unit thickness: Cerro de Cristo Rey (12 m thick)
Type locality: none. Is uppermost formation of Washita Group at top of Comanche Series southward to Colorado River and continuing southwestward to the Rio Grande.
Correlation:
Lithologies: Limestone, marly limestone, shale, sand stringers; a resistent unit
Fossils: Gastropods abundant; a few *Gryphea*
Depositional environment:
Stratigraphic relations to underlying units or predecessors:
Stratigraphic relations to overlying units or successive rocks: Boquillas Formation
Commodities: Small manganese deposit is present along a fault zone

Bull Canyon basaltic andesite (Reiter, 1980)
Age: 29.62+0.62 m.y. (Reiter, 1980)
Occurrence/thickness: Alamo-Hueco Mountains (up to 153 m thick)
Type locality: none; described from Bull Canyon, Alamo-Hueco Mountains
Correlation: Basalt of Whitewater Mountains of Erb (1979)
Lithologies: porphyritic basaltic andesite
Fossils: n.a.
Depositional environment: Multiple flows
Stratigraphic relations to underlying units or predecessors: Unconformable on Gillespie and Oak Creek tuffs
Stratigraphic relations to overlying units or successive rocks: Conformable with Park Tuff
Commodities:

Bullard Peak series of Hewitt (1959)(Hewitt, 1959; Hedlund, 1978)
Age: Precambrian Y, Proterozoic
Occurrence/thickness: Burro Peak quad, Soldiers Farewell Hill quad, Ninetysix Ranch quad, Gold Hill quad, Werney Hill quad, C Bar Ranch quadrangle; Big Burro Mountains-Redrock area, Little Burro Mountains;
Type locality: none
Correlation:
Lithologies: Hornblende gneiss and amphibolite, quartz-biotite gneiss and migmatite, quartzite, schist
Fossils: n.a.

Depositional environment:
Stratigraphic relations to underlying units or predecessors:
Stratigraphic relations to overlying units or successive rocks:
Commodities: see Black Hawk mining district;White Signal district; Gold Hill district; Burro Mountains district

Burro Mountains granite (Kolesaar, 1982)
Age: Precambrian; 1550 m.y.; Hedlund, 1978b
Occurrence/thickness: Big Burro Mountains area (batholith)
Type locality: Big Burro Mountains
Correlation:
Lithologies: medium- to coarse-grained equigranular granite; locally porphyritic. Color, texture, mineral and chemical composition, fracturing and jointing, and degree of weathering and alteration are variable (Gillerman, 1970). Mineralized along the Malone Fault, Malone mining district; Telegraph mine area, Telegraph district
Fossils: n.a.
Depositional environment:
Stratigraphic relations to underlying units or predecessors:
Stratigraphic relations to overlying units or successive rocks:
Commodities: rare-earth element pegmatites; see Gold Hill district, White Signal district, Telegraph district, Malone district; copper and uranium minerals, Burro Mountains district

Bursum Formation (Wilpolt and others, 1946; Kottlowski and others, 1956; Pray, 1959; Myers, 1973; Maxwell and Oakman, 1990)
Age: Early Permian, Wolfcampian (Wilpolt and others, 1946; Kottlowski and others, 1956; Maxwell and Oakman, 1990)
Occurrence/unit thickness: Used as a label for Wolfcampian age beds throughout central and south-central New Mexico; may represent the transitional beds between the Abo red beds and Hueco marine limestones. Isopachs of the Abo, Earp, and Hueco-Horquilla facies in southern N. Mex., the Mesozoic eroded edge, and the Burro Uplift, are given in Kottlowski (1963, fig. 9): 81 m, northern San Andres Mountains pinching out southward near Deadman Canyon. Doña Ana Mountains (questioned occurrence; 61 m at Grande Dome), Organ/San Andres Mountains, Robledo Mountains (58 m)
Type locality: SE1/4, sec 1, T. 6 S., R. 4 E., just west of Bursum triangulation station, Socorro County, in the western foothills of Oscura Mountains (Wilpolt and others, 1946). Named as upper formation of the Magdalena Group.
Correlated with: uppermost Panther Seep beds, southern San Andres Mountains, may be correlative (Kottlowski and LeMone, 1994).
Lithologies: intertongued red beds and marine limestone; micrite and biomicrite, algal biolithites, chert and limestone pebble conglomerate; petrified wood, algae, corals, gastropods, crinoids
Fossils: main guide fossils fusulinids *Triticites* and *Schwagerina*
Depositional environment: normal marine to basinal marine rock
Stratigraphic relations to underlying units or predecessors: In San Andres Mountains, basal arkosic and conglomeratic beds cut into the Panther Seep Formation
Stratigraphic relations to overlying units or successive rocks: unconformity with overlying middle and upper Wolfcampian Hueco Formation
Commodities: Potential for high-calcium limestone and marble

Caballero Formation
Age: Early Mississippian (late Kinderhookian) (Laudon and Bowsher, 1941, 1949; Kottlowski, 1963; Gordon, 1986)
Occurrence/unit thickness: Black Range, Cookes Range (15 m thick), and Fluorite Ridge area (11-21 m thick), southern Organ Mountains and Bishop Cap (up to 9 m thick), San Andres Mountains, Robledo Mountains (34 m). Not recognized in the Cobre Uplift. Thins to the north and south from Lake Valley (Sierra County). Isopachs of the Caballero Basin in southern N. Mex., the Jarilla Uplift(?), and the Burro Uplift, are given in Kottlowski (1963, fig. 8).
Type locality: Deadman Canon, sec. 3, T. 17 S, R. 10 E., Otero County (Laudon and Bowsher, 1941)
Lithologies: Interbedded sandy, nodular, arenaceous, fossiliferous, shaly limestone and dolomite; silty shale; calcareous, dolomitic siltstone.
Thickness of beds; structures: Thin-bedded.
Fossils: crinoids
Depositional environment: shallow marine deposit.
Stratigraphic relations to underlying units or predecessors: Locally unconformable on underlying Devonian rocks. In the Bishop Cap and southern San Andres Mountains, it appears conformable on the Percha Shale (Seager, 1981).

Cable Canyon Sandstone (Montoya Group) (Kelley, 1951; Kelley and Silver, 1952; Zeller, 1965; Thorman and Drewes, 1981; Drewes, 1991)
Age: Middle Ordovician, Champlainian
Correlated with: Unit mapped as the lower part of the Second Value Dolomite, Silver City Range (Cunningham, 1974; Hayes, 1975).
Occurrence/unit thickness: Cedar Mountains area (up to about 10 m); Florida Mountains; Big Hatchet Mountains (5 m thick); Robledo Mountains (4.5 m thick); Organ-San Andres Mountains (Montoya Group), Pinos Altos/Silver City Range (32 m); Victorio Mountains; Klondike Hills. Isopachs of the Montoya Dolomite and Cable Canyon Sandstone in southwestern N. Mex. are given in Kottlowski (1963, fig. 5).
Type locality: Opposite Sierrite Mine at head of Cable Canyon, NW1/4 sec 10 T. 16 S., R. 4 W., Caballo Mountains, Sierra Co (Kelley and Silver, 1952)
Lithologies: Fossiliferous arenaceous dolomitized calcarenite and pebbly dolomitic sandstone and sandy dolomite. Coarse sand grains are rounded to subrounded, frosted, and cemented by silica or dolomite.
Fossils: marine fauna
Depositional environment: Partly eolian. A sandwave complex that began during initial marine transgressive stage.
Alteration: Thermally metamorphosed to quartzite adjacent to the Organ batholith.
Stratigraphic relations to overlying units or successive rocks: Cable Canyon Sandstone grades into the Upham as a transgressive basal sand (Seager, 1981).
Commodities: Rincon District: Bat Cave Member, manganese deposits

Camp Rice Formation
Age: Quaternary, Pleistocene
Occurrence/unit thickness: Bishop Cap; Doña Ana Mountains; Franklin Mountains; Rincon Hills; Rough and Ready Hills; Sierra de las Uvas
Type locality:
Correlation:

Lithologies: sand and gravel, mainly unconsolidated to weakly indurated
Fossils:
Depositional environment: fluvial, fanglomerate eolian, terrace, piedmont slope
Stratigraphic relations to underlying units or predecessors:
Stratigraphic relations to overlying units or successors:
Commodities: Sand, gravel, caliche, clay

Canutillo Formation (Nelson, 1940; Stevenson, 1945; Laudon and Bowsher, 1949, Seager, 1981)
Age: Late Devonian
Occurrence/unit thickness: Organ Mountains, northern Franklin Mountains (35 m thick, thinning northward), Bishop Cap (14 m thick). Pinches out in southern San Andres Mountains. Isopachs of the Canutillo in southwestern N. Mex., the Jarilla Uplift(?), and the Burro Uplift, are given in Kottlowski (1963, fig. 7).
Type locality: none
Correlation: Originally, the Canutillo consisted of all Devonian rocks in the Franklin Mountains (Nelson, 1940), but later workers in the Franklin Mountains in Texas (Laudon and Bowsher, 1949) assigned the upper part to the Percha Shale, based on fossil and lithologic evidence.
Lithologies: Fissile siltstone, shale, and cherty limestone and dolomite, calcareous or dolomitic siltstone. The lowermost beds consist of chert and marl.
Fossils: Brachiopods and conodonts.
Depositional environment: Marine. The Canutillo is a channeled surface marked by potholes (Harbour, 1972).
Stratigraphic relations to underlying units or predecessors: Unconformable on Fussleman Dolomite.
Stratigraphic relations to overlying units or successive rocks: Underlies the Percha Shale conformably; it grades upward into the Percha in the Franklin Mountains.
Commodities:

Carbonate Hill Limestone (Bisbee Group)(Gillerman, 1958; Hayes, 1970; Armstrong and others, 1978; Drewes, 1986)
Age:
Occurrence/thickness:
Type locality: Named for exposure near Carbonate Hill Mine, sec. 34, T. 24 S., R. 21 W., Hidalgo Co (Gillerman, 1958)
Correlation:
Lithology:
Fossils:
Depositional environment:
Stratigraphic relations to underlying units or predecessors:
Stratigraphic relations to overlying units or successive rocks:
Commodities: High-calcium limestone locally

Castner Limestone (Harbour, 1960, 1972)
Age: Precambrian, Proterozoic
Occurrence/thickness: Franklin Mountains

Type locality: 0.5 m southeast of North Franklin Mountain and 0.15 m northwest of mouth of Fusselman Canyon, El Paso Co. TX; named for Castner Range located in Fort Bliss Military Reservation (Harbour, 1960)
Correlation:
Lithology: locally metamorphosed limestone
Fossils:
Depositional environment:
Stratigraphic relations to underlying units or predecessors:
Stratigraphic relations to overlying units or successive rocks:
Commodities: Northern Franklin Mountains District: Copper contact metasomatic deposits; replacement iron deposits in this unit in Texas

Cedar Hill Andesite (Zeller and Alper, 1965; Brooks and others, 1989)
Age: Tertiary, Oligocene
Occurrence/thickness: Animas Mountains
Type locality: none; probably named for Cedar Hill, sec 12, T. 31 S., R. 18 W., where it is well exposed (Zeller and Alper, 1965)
Correlation:
Lithology: Andesite
Fossils: n.a.
Depositional environment: Intrusive
Stratigraphic relations to underlying rocks or predecessors:
Stratigraphic relations to overlying rocks
Commodities:

Center Peak Latite (Zeller, 1962; Zeller and Alper, 1965)
Age: Tertiary
Occurrence/thickness: Animas Mountains
Type locality: none. Confined within a radius of several mi of Center Peak, sec. 5, T. 31 S., R. 18 W., southwest part of Walnut Wells quad, Hidalgo Co. (Zeller and Alper, 1965)
Correlation:
Lithology: Andesite, latite
Fossils: n.a.
Depositional environment: flow
Stratigraphic relations to underlying rocks or predecessor(s): Paleozoic carbonates and/or Cretaceous clastic rocks in Fremont Mining district, Sierra Rica
Stratigraphic relations to overlying rocks or successor(s):
Commodities:

Chapo Formation (Peterson, 1976; Deal and others, 1978)
Age: 30.66+1.15 m.y. old (K-feldspar, K-Ar; Deal and others, 1978)
Occurrence/thickness: Sierra Rica/Apache Hills
Type locality: none.
Correlation:
Lithology:
Fossils: n.a.
Depositional environment: volcanic rocks
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):

Commodities:

Cintura Formation (Bisbee Group) (Ransome,1904; Imlay, 1939; Hayes, 1970, Cooper and Silver, 1964; Hayes and Raup, 1968; Drewes and Thorman, 1980; Hayes, 1970, 1982; Drewes, 1986)
Age: Early Cretaceous
Occurrence/thickness: Central Animas Mountains (as much as 305 m thick); Peloncillo Mountains (700 m thick); Sierra Rica. and Apache Hills; Tres Hermanas Mountains (West Lime Hills)
Type locality: none. Named for Cintura Hill near north edga of Bisbee 15–min quad, Cochise Co. (Ransome, 1904). Named as top formation of Bisbee Group
Correlation: Correlative with the Mojado Formation in the Sierra Rica.
Lithology: shale, siltstone, and sandstone
Fossils:
Depositional environment:
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities:

Clanton Draw, rhyolite of (ref)
Age:
Occurrence/thickness: Peloncillo (Geronimo Trail caldera)
Type locality:
Correlation:
Lithology:
Fossils:
Depositional environment:
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities:

Cleofas Andesite (Seager, Kottlowski, and Hawley, 1976)
Age: Eocene
Occurrence/thickness: central Doña Ana Mountains
Type locality:
Correlation: May be a source for part of the Palm Park Formation with which it is probably correlative.
Lithology: Andesite; generally porphyritic and phenocrysts comprise 75-80 percent of the rock.
Fossils:
Depositional environment: Mostly an intrusive.
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s): Unconformable with middle Oligocene volcanic rocks.
Commodities: Piedra Blanca prospect, volcanic epithermal deposits of Doña Ana Mountains District

Colina Limestone Naco Group (Gilluly, Cooper and Williams, 1954; Sabins, 1957; Gillerman, 1958; Zeller, 1958, 1962, 1965; Cooper and Silver, 1964; Creasey, 1967; Hayes and Raup,

1968; Butler, 1971; Simons, 1974; Drewes, 1971, 1975; 1991; Armstrong and others, 1978; Drewes and Thorman, 1980)

Age: Early Permian, Wolfcampian and Leonardian? (biostratigraphic dating)

Occurrence/unit thickness: Animas Mountains (lower part of the Colina); Big Hatchet Mountains (107-153 m thick); Peloncillo Mountains (at least 119 m thick), Tres Hermanas Mountains (West Lime Hills). Exposed in Winkler Anticline, Animas Mountains. Isopachs of the Abo, Earp, and Hueco-Horquilla facies in southern N. Mex., the Mesozoic eroded edge, and the Burro Uplift, are given in Kottlowski (1963, fig. 9).

Type locality: section: on the west side of Colina Ridge 0.5 km south of Horquilla Peak in the Tombstone Hills, Cochise Co. AZ (Gilluly and others, 1954). Named as a formation of Naco Group.

Correlation:

Lithologies: Limestone, sparse chert

Fossils: Gastropods, pelecypods, and echinoid spines. Commonly contain algal mats, gypsum pseudomorphs, mudcracks, bird's eye structures

Depositional environment: Shallow water to subaerial, probably in a subtidal to supratidal environment.

Stratigraphic relations to underlying units or predecessors: Conformable with Earp Formation

Stratigraphic relations to overlying units or successive rocks: Unconformable

Commodities: high-calcium limestone may be present locally.

Colorado Formation (Paige, 1916; Darton, 1916; Lasky, 1936; Wargo, 1959; Jones and others, 1970; Hayes, 1970; Cunningham, 1974; Hook and others, 1983; Kaczmarek, 1987; Cobban, 1988; Cobban and others, 1989; Hedlund, 1990b; Morrison, 1965

Subunits: Pinos Altos Range/Silver City Range (probably exceeds 305 m); sandstone member, shale member, and undivided member. Cookes Range (92 m thick); Bridge Creek Limestone Member (Hook and Cobban, 1981; Cobban and others, 1989).

Age: Early to Late Cretaceous; Cenomanian to Turonian

Occurrence/unit thickness: Cookes Range (approximately 92 m thick); Steeple Rock area (244 m thick); Pinos Altos Range/Silver City Range (0-671 m thick); best exposed at Santa Rita (113 m thick; Jones and others, 1967). Crops out in the Big Burros (336 m thick; Hewitt, 1959) and Little Burros (48 m thick; Edwards, 1961)(Kaczamarek 1987). Intruded by concordant sheets of igneous rock and by innumerable thin dikes and sills. Crops out in Chino pit. Mainly eroded from area south of Barringer Fault, but present north of the fault.

Type locality: None. Consists of Niobrara Formation, Carlile Shale, Greenhorn Limestone (Formation), and Graneros Shale

Correlation: Probably correlative with the Mancos Shale in Caballo Mountains, Jornada del Muerto, and areas to the north of the study area. In the Pinos Altos Range/Silver City Range, shale member may be equivalent of the Graneros Shale, and the sandstone member (with limestone) may be age-equivalent to the Mesaverde Formation and the Greenhorn Limestone. Molenaar (1983) recommends the tripartite Colorado Formation in the Silver City-Cookes Range be replaced with (bottom to top) Mancos Shale, Atarque Sandstone, and Moreno Hill Formation (formation names used in San Juan Basin in northwestern New Mexico); recommends abandonment of the Colorado Formation in New Mexico.

Lithologies: blocky dark shale, limestone, silty or sandy shale, interbeds of sandstone. May be metamorphosed by localized intrusions and structural features.

Fossils: scarce, except locally. Carbonized plant debris; fossilized wood. Mollusks, pelecypods, and ammonites in (marine) limestone beds.

Depositional environment: Marine and non-marine; transgressive-regressive cycle. Northeasterly paleoslope, with marine longshore current to the northwest (Kaczamarek, 1987).
Stratigraphic relations to underlying units or predecessors: Conformable on Beartooth Quartzite; disconformable on the Sarten Sandstone in eastern Cookes Range.
Stratigraphic relations to overlying units or successive rocks: Unconformable with Tertiary rocks in Pinos Altos Range/Silver City Range.
Commodities: Supergene copper mineralization at Continental mine (associated with the Hanover Mountain porphyry). Porphyry-copper-associated copper-sulfide deposits, Santa Rita district.

Concha Limestone Naco Group; (Gilluly and others, 1954; Wrucke and others, 1983; Sabins, 1957; Bryant and McClymonds, 1961; Cooper and Silver, 1964; Hayes and Raup, 1968; Butler, 1971; Wrucke and others, 1983; Dane and Bachman, 1961; Zeller, 1962, 1965; Drewes, 1971, 1975, 1991; Armstrong and others, 1978)
Age: Early to Late(?) Permian
Occurrence/unit thickness: Thickest in the Big Hatchet Mountains (about 287 m thick); Peloncillo Mountains (at least 150 m thick); Animas Mountains (about 60 m thick). Crops out south of the Alamo Hueco Mountains (at Rancho las Palmas) Isopachs and facies of the Concha (including Rainvalley) in southern N. Mex., Mesozoic eroded edge, and the southern limit of Triassic rocks, are given in Kottlowski (1963, fig. 16).
Type locality: on east end of Concha Ridge in the Gunnison Hills, NW 1/4, sec 28, T. 15 S., R. 23 E., Cochise Co. AZ (Gilluly and others, 1954). Named as a formation of the Naco Group.
Correlation:
Lithologies: Clastic limestone, chert nodules, silicified fossils (brachiopod; locally dolomitic
Fossils: Brachiopods (productids), fusulinids
Depositional environment: In the subsurface the unit may be cavernous, probably indicating karstic solution and (or) erosion in pre-Cretaceous time.
Stratigraphic relations to underlying units or predecessors: Probably disconformable on the Scherrer Formation.
Stratigraphic relations to overlying units or successors:
Commodities: Adjacent to intrusions, metamorphosed to white marble.

Cooney Tuff (Ratté and others, 1979; Ratté, 1981; Marvin and others, 1987; Strangway and others, 1976; McIntosh and others, 1992)
Age: Tertiary, Oligocene; 32± 1.5 m.y. (Bikerman, 1972; Marvin and others, 1987)
Occurrence/unit thickness: Mogollon Mountains; northern part of the Mogollon-Datil volcanic field, outside of the Mimbres Resource Area (0-610+ m thick)
Type locality: S1/2, sec. 21, T. 10 S., R. 19 W., Catron Co. (Ratté, 1981)
Correlation/subdivisions: Divided into the Whitewater Creek (base) and Cooney Canyn (new, top) members (Ratté, 1981)
Lithology: quartz latite
Fossils:
Depositional environment: a widespread tuff that erupted from an unknown caldera; densely to partially welded ash-flow tuff; pre-caldera rocks of the Gila Cliff Dwellings and Bursum calderas
Stratigraphic relations with underlying rocks or precursors:
Stratigraphic relations with overlying rocks or successors:
Commodities:

Cooney Canyon Member (Cooney Tuff) (Ratté,1981)
Age: Tertiary, Oligocene
Occurrence/unit thickness: Mogollon Mountains
Type locality: S 1/2, sec 20, T. 10 S., R. 19 W., Mogollon quad, Catron Co. (Ratté, 1981)
Correlation:
Lithology:
Fossils:
Depositional environment:
Stratigraphic relations with underlying rocks or precursors:
Stratigraphic relations with overlying rocks or successors:
Commodities:

Corbett Sandstone (Bisbee Group)(Lasky, 1938; Zeller, 1970; Hayes, 1970)
Age: Early Cretaceous
Occurrence/thickness:
Type locality: None designated. Named for Corbett Ranch at south end of the Little Hatchet Mountains, Hidalgo County
Correlation:
Lithology:
Fossils:
Depositional environment:
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities:

Courchesne Formation of Strain (1968) (Strain, 1968; Lovejoy, 1976)
Age: Cretaceous
Occurrence/unit thickness: Cerro de Cristo Rey
Type locality:
Correlation: Finlay Limestone
Lithology: sedimentary rock
Fossils:
Depositional environment: sedimentary
Stratigraphic relations with underlying rocks or precursors:
Stratigraphic relations with overlying rocks or successors:
Commodities: Limestone (93.3 percent calciium carbonate)

Cowboy Rim, quartz latite of
Age:
Occurrence/unit thickness: Animas
Type locality:
Correlation:
Lithology:
Fossils:
Depositional environment:
Stratigraphic relations with underlying rocks or precursors:
Stratigraphic relations with overlying rocks or successors:
Commodities:

Cowboy Spring Formation (Zeller and Alper, 1965; Hayes,1970; Elston and Erb, 1977; Zeller, 1976)
Age: Early, Late Cretaceous; Albian and Cenomanian
Occurrence/unit thickness: Animas
Type locality: Secs 13,24, T. 31 S., R. 18 W., secs 18, 19, T. 31 S., R. 17 W., Hidalgo Co (Zeller, 1976)
Correlation:
Lithology:
Fossils:
Depositional environment:
Stratigraphic relations with underlying rocks or precursors:
Stratigraphic relations with overlying rocks or successors:
Commodities:

Crookson Peak, lava flows of
Age:
Occurrence/unit thickness: Steeple Rock area, from Apache Box southward to Crookson and Juniper Peaks (maximum thickness is about 460 m)
Type locality:
Correlation: brown andesite porphyry of Biggerstaff (1974) and Griggs and Wagner (1966)
Lithology: dacite and andesite
Fossils:
Depositional environment: lava flows
Stratigraphic relations with underlying rocks or precursors: unconformable with Dark Thunder Canyon formation in Steeple Rock area
Stratigraphic relations with overlying rocks or successors:
Commodities:

Cueva Rhyolite (Dunham, 1935) (Cueva Tuff**,** Seager, 1981)
Age: Tertiary, 33.0 m.y.; 33.7 m.y. (Seager, 1981)
Occurrence/thickness: Southern Organ Mountains. Organ (Organ caldera). From 31 m thick to as thick as 412 m at Peña Blanca
Type locality: La Cueva, for which unit is probably named, west of mouth of Fillmore Canyon in Organ Mountains, Doña Ana County. Cueva rock, mouth of Fillmore Canyon, Organ-San Andres Mountains (Dunham, 1935)
Subunit name: Peña Blanca tuff (Seager, 1981); tuff of Cox Ranch (Seager, 1981)
Correlated with: May be comagmatic with Organ Batholith.
Lithologies: Rhyolite
Fossils: n.a.
Depositional environment: Ash-flow tuff; ring–fracture and moat deposits. Compound and simple cooling units. Source is Organ caldera.
Stratigraphic relations to underlying units or predecessors: Orejon Andesite
Stratigraphic relations to overlying units or successive rocks: tuff of Cox Ranch, Soledad Rhyolite (Organ caldera)
Commodities:

Cutter Dolomite (Montoya Group)(Kelley and Silver, 1952; Zeller, 1965; Drewes, 1991)
Age: Late Ordovician; Cincinnatian

Occurrence/thickness: Animas Mountains (98 m thick); Big Hatchet Mountains (72 m thick); Organ Mountains (48 m thick); Robledo Mountains (47 m thick); southern San Andres Mountains (31-38 m thick); Piños Altos/Silver City Range (12 m thick); Victorio Mountains

Type locality: Opposite the Sierrite Mine athead of Cable Canon, NW 1/4, sec 10,T. 16 S., R. 4 W., Caballo Mountains, Sierra Co (Kelley and Silver, 1952). Named as a formation of Montoya Group.

Correlation:

Lithologies: Calcareous dolomite with localized nodules and lenses of chert. In the Organ and San Andres Mountains, the uppermost beds are chert-free, fine-grained dolomite. In Animas Mountains, the unit is dolomite with interbeds of quartz sand-bearing dolomite and cherty dolomite.

Fossils: In the Big Hatchet Mountains, extensively burrowed with brachiopod fragments. In the northern Animas Mountains, contains rhynconellid brachiopods locally.

Depositional environment:

Stratigraphic relations to underlying units or predecessors:

Stratigraphic relations to overlying units or successive rocks:

Commodities:

Dakota Sandstone (Meek and Hayden, 1862; Winchester, 1920; Kottlowski, 1963; Hook, 1983; Moore and others, 1988)

Age: late Early Cretaceous to early Late Cretaceous

Occurrence/unit thickness: Southern San Andres Mountains (Sarten-Dakota), west of Love Ranch (56 m thick; (Kottlowski and LeMone, 1994)]; Big Burro Mountains area (Virden), (18-46 m thick)

Type locality: Not originally designated. Occurs in hills near town of Dakota, Dakota Co. NE (Meek and Hayden, 1862).

Correlation: A similar unit has been designated as Sarten Sandstone and Beartooth Quartzite, undifferentiated, in the vicinity of the Cobre Uplift (15-43 m thick), Cookes Range (92 m thick), and Steeple Rock area (18 m thick). Sarten Sandstone may be correlative with Beartooth Quartzite in the Pinos Altos Range/Silver City Range. Molenaar (1990) states that the Beartooth is probably coeval to or slightly older than the Dakota in south-central New Mexico.

Lithologies: Southern San Andres Mountains north of Love Ranch; gray, resistant, quartzite, weathered sandstone, locally nodular and platy; interbedded black shale; basal discontinuous chert-pebble conglomerate.

Fossils:

Depositional environment: nearshore marine. Sources for the Beartooth and Dakota sandstones may have been partly derived locally, but paleocurrent analysis suggests a source terrane to the west-southwest.

Stratigraphic relations to underlying units or predecessors: overlies Yeso-San Andres Formations; Big Burro Mountains area (Virden), nonconformable on Precambrian

Stratigraphic relations to overlying units or successive rocks: Disconformable with Mancos shale

Commodities: Silica flux (Sarten Sandstone)

Dark Thunder Canyon formation (Griggs and Wagner, 1966; Biggerstaff, 1974)

Age:

Occurrence/thickness: Steeple Rock area

Type locality:

Correlation: basaltic and andesitic rocks of Dark Thunder Canyon (Hedlund, 1990, 1993)
Lithology: andesite and basaltic andesite interbedded with tuff and volcaniclastic sandstone
Fossils:
Depositional environment: volcanic flows, tuffs
Stratigraphic relations to underlying rocks or predecessor(s): unconformable with Bloodgood Canyon Tuff, Summit Mountains formation
Stratigraphic relations to overlying rocks or successor(s): unconformable with lava flows of Crookson Peak
Commodities:

Davis Canyon Tuff (Ratté, 1981; Marvin and others, 1987; Ratté and others, 1979; Ratté, Bove, and McIntosh, 199–)
Age: Tertiary, Oligocene [29.0 Ma: McIntosh and others (1990,a,b; 1991)]
Occurrence/thickness: Mogollon Mountains, southwestern Mogollon-Datil field; Gila Primitive Area and Gila Wilderness; 0-92 m thick; 10,497 km^2; Summit Mountains east of Steeple Rock
Type locality: S1/2, sec 11, T. 13 S., R. 17 W., Shelley Peak quad, Catron Co (Ratté, 1981)
Correlation:
Lithology: In Steeple Rock area, characterized by coarse, tringly pumice fragments up to several mm long; lithic fragments of andesite up to several cm, and andesite, rhyolite, and tuff boulders up to one m in diameter present locally
Fossils:
Depositional environment: Episode 3 ignimbrite, Mogollon-Datil volcanic field. Source uncertain; may be in the Gila Cliff Dwellings or Bursum calderas. Probably pre-caldera rocks of the Gila Cliff Dwellings and Bursum calderas.
Stratigraphic relations to underlying units or predecessors: coextensive and gradational with the Shelley Peak Tuff; unconformably overlies the Summit Mountains formation.
Stratigraphic relations to overlying units or successive rocks: unconformable with the Bloodgood Canyon Tuff
Commodities:

Del Norte Formation (Strain, 1976; Lovejoy, 1976)
Subunit: Refinery member (upper), Brick Plant member (lower)
Age: Early Cretaceous, Comanchean and Albian
Occurrence/unit thickness: Cerro de Cristo Rey (17.2 m thick)
Type locality: NW1/4 sec 15, T. 29 S., R. 4 E, Smeltertown quadrangle, Dona Ana County. Named for Rio Bravo del Norte (Rio Grande)(Strain, 1976)
Lithologies: limestone, calcareous shale
Fossils: fossiliferous
Depositional environment:
Stratigraphic relations to underlying units or predecessors: Finlay Formation
Stratigraphic relations to overlying units or successors:
Commodities:

Del Rio Clay (Adkins, 1932; Bullard, 1953; Lovejoy, 1976) [formerly called *Exogyra arietina* Marl (Shumard, 1860]
Age: Late Cretaceous, Albian; Washita Group
Occurrence/unit thickness: Cerro de Cristo Rey (24-28 m thick). Incompetent shale unit that is preserved only below Buda limestone

Type locality: a low,conical butte, Loma de la Cruz, and surrounding clay lowlands 3.2 km south of Del Rio, Val Verde Co., TX (Adkins, 1932)
Correlation:
Lithologies: shale, calcareous shale, limestone
Fossils: *Exogyra* (pelecypods) mark lower part of formation
Depositional environment:
Stratigraphic relations to underlying units or predecessors: Anapra Formation
Stratigraphic relations to overlying units or successive rocks: Buda Formation
Commodities:

Doña Ana rhyolite (Seager, Kottlowski, and Hawley, 1976)
Age: Oligocene
Occurrence: Doña Ana Mountains (as thick as 763 m). Not recognized in the Bell Top Formation of the Sierra de las Uvas-Cedar Hills area, nor in the Organ Mountains.
Type locality:
Correlation:
Lithologies: Rhyolite, with associated rhyolitic to monzonitic intrusives and lesser and more densely welded units.
Fossils:
Depositional environment: Doña Ana caldera fill; emitted from the Doña Ana caldera and caused its formation and subsequent collapse. Air-fall tuff, ash-flow tuff, welded tuff, intrusive ignimbrite, plug-dome complexes. Main rock unit of the Doña Ana caldera
Stratigraphic relations to underlying units or predecessors: Unconformable
Stratigraphic relations to overlying units or successive rocks: Unconformable. Overlain by unnamed caldera-fill deposits and rhyolite. Cut by monzonite porphyry dikes and related rocks.
Commodities: Potential for perlite, pumice, clay, zeolite

Earp Formation; Naco Group (Gilluly and others, 1954; Gilluly, 1956; Sabins, 1957; Gillerman, 1958; Sabins and Ross, 1963; Cooper and Silver, 1964; Hayes and Raup, 1968; Butler, 1971; Zeller, 1962, 1965; Drewes and Thorman, 1980; Drewes, 1971, 1975, 1987, 1991; Armstrong and others, 1978)
Age: Wolfcampian; Early Permian (local) and Late Pennsylvanian (local)
Correlated with: Abo Formation to the east (Clemons and Mack, 1988)
Occurrence/unit thickness: Described from Animas Mountains (as much as 187 m thick); Big Hatchet Mountains (about 305 m thick); Peloncillo Mountains (about 244 m thick). Tentatively identified in the Little Hatchet Mountains (questioned occurrence; Zeller, 1970) as a metamorphosed beds of siltstone and dolomite in contact with Horquilla, but it is stated that these units could be clastic units within the Horquilla. Isopachs of the Abo, Earp, and Hueco-Horquilla facies in southern N. Mex., the Mesozoic eroded edge, and the Burro Uplift, are given in Kottlowski (1963, fig. 9). In the Central Peloncillo Mountains, it is metamorphosed and (or) faulted; thickness measurements are only approximate. In the Animas Mountains, it is exposed in the Winkler Anticline.
Type locality: extends from saddle south of Earp Hill; sec 5, T 21 S., R. 23 E., Cochise Co. AZ (Gilluly and others, 1954)
Lithologies: siltstone, marlstone, shale, some thin lenses of limestone. Minor dolomitic siltstone and mudstone, dolomite, calcareous nodules.
Fossils: foraminifera, fusulinids, conifer wood, fish scales, and other trace fossils.

Depositional environment: marine and nonmarine, including intertidal red beds and other siliciclastics.

Stratigraphic relations to underlying units or predecessors: Typically conformable with Horquilla Limestone. In the central Peloncillo Mountains, gradational into Horquilla. Disconformable on Horquilla in Animas Mountains.

Stratigraphic relations to overlying units or successive rocks: Conformable with Colina, Epitaph, and Scherrer Formations in Animas Mountains.

Commodities: Host for Gillespie mine deposits

El Paso Limestone (Richardson, 1904, 1908; Darton, 1916; Paige, 1916; Kelley, 1951; Gillerman, 1958; Kelley and Silver, 1952; Kottlowski, 1963; Zeller, 1965; LeMone, 1969; Blankenship, 1972; Hayes, 1972, 1975; Maxwell and Oakman, 1990; Hedlund, 1978, Werney Hill quad; Seager, 1981; Clemons; 1987; Drewes, 1991; Armstrong and others, 1978); Drewes, du Bray, and Pallister, 1995

Age: Early Ordovician (Canadian) and Late Cambrian (Croixan)

Occurrence/thickness: Animas Mountains (as much as 183 m thick), Big Hatchet Mountains (279-326 m thick), Bishop Cap (surface and subsurface), Black Range (153 m thick), Black Mountains/Knight Peak area (20 mthick. incomplete sections), Cedar Mountains area (exceeds 100 m), Cobre Uplift (153 m thick), Cookes Range (253 m thick), East Potrillo Mountains, Florida Mountains (up to 385 m thick), Franklin Mountains (427 m thick in southern part in Texas; 30 m thick in northern part in NM), Klondike Hills, Knight Peak area, Organ Mountains (305 m thick), central Peloncillo Mountains (180 m thick), Pinos Altos Range/Silver City Range (153-158 m thick), Robledo Mountains (at least 50 m thick on surface, extending into subsurface), San Andres Mountains (238 m thick), San Diego Mountain, west side of Sierra Rica, Tonuco Uplift (92 m thick), Victorio Mountains (79 m thick). About 76 m thick in Werney Hill quad, southeast of Big Burro Mountains (Hedlund, 1978).

Type locality: None. Derivation of name not stated (Richardson, 1904)

Correlation: Time-transgressive from east to west (Lemone, 1974). In the west, the unit is not subdivided into mappable units and is the "El Paso formation" to some workers. In the eastern part of the study area, it is subdivided into lithologic units and called the "El Paso Group" by some workers. In the Franklin Mountains, subdivided into (base to top) Sierrite, Cooks, Victorio Hills, José, McKelligon, Scenic Drive, and Florida Mountains Formations. Zeller (1965) described a lower Sierrite Member and and upper Bat Cave Member in the Big Hatchet Mountains. Blankenship (1972) describes three members in the Silver City area, the lowest member possibly equivalent to the Sierrite Member. Sierrite Limestone has been described frojm the San Diego Mountain/Tonuco Uplift region (Seager, 1975). Recent work in southern New Mexico subdivides the unit into four members, from base to top: Hitt Canyon, Jose, McKelligon, and Padre (Clemons and Mack, 1988). Isopachs of the three uppermost zones of the El Paso Limestone are shown by Kottlowski (1963; fig. 4). In the Peloncillo Mountains, it is mapped with the Montoya Group. It is partially equivalent to the Ellenberger Group, Permian Basin.

Lithologies: Calcareous and dolomitic rocks; locally contains pebble conglomerate, sandstone, chert, arenite, clay, and oolites. Glauconite, cherty, or siliceous at the base locally. In Cookes Range, basal unit is black oolitic limestone.

Fossils: Nautiloids, brachiopods, gastropods, stromatolites, trilobites, sponges, and pelmatozoan (echinoderm) fragments, trace fossils, cystoid plates, stromatolites and sponges in reefs, and oolitic, pelletiferous, and algal beds.

Depositional environment: Interpreted to be a tidal or intertidal shallow-water shelf deposit.

Stratigraphic relations to underlying units or predecessors: Conformable with, and grades into, Bliss Sandstone.
Stratigraphic relations to overlying units or successive rocks: Commonly unconformable with Tertiary fanglomerate. Northward from the Robledo Mountains, erosionally thinned. Disconformable to conformable with Montoya in Pinos Altos Range/Silver City Range, and Florida Mountains; disconformable with Montoya in Organ–San Andres Mountains as a result of uplift, southward tilting, and erosion of pre–Montoya Group rocks.
Commodities: High-calcium limestone locally, extent not known. Locally thermally metamorphosed to massive marble near the Organ batholith. Unit commonly contains magnesium silicates. Locally silicified. Dolomitized at Bishop Cap and locally in San Andres Mountains. Black Mountain District, Organ Mountains: Sedimentary-hydrothermal barite-fluorite-galena deposits, Black Mountain district. San Andrecito-Hembrillo District: Vein- and replacement-deposits. Rincon District: Bat Cave Member, manganese deposits. Iron deposits at Fierro Hanover. Fluorite in Fleming district. In Klondike Hills, silica, copper, lead mineralization and jasperoids. Manganiferous iron ore in the Chloride district (Boston Hill and Chloride Flat mines) is an intimate mixture of hematite and pyrolusite.

Emory Canyon andesite (Reiter, 1980)*f*
Age: Tertiary
Occurrence/unit thickness: Alamo-Hueco Mountains
Type locality: Emory Canyon, northeastern flank of Alamo-Hueco Mountains
Correlation:
Lithologies: basaltic andesite, vesicular, porphyritic; massive breccia
Fossils:
Depositional environment: 1-3-m-thick flows and breccias (breccia is probably an autobrecciated lava flow)
Stratigraphic relations to underlying units or predecessors: conformable or unconformable with mudflow and lake deposits
Stratigraphic relations to overlying units or successors:
Commodities:

Epitaph Dolomite; Naco Group (Gilluly and others, 1954; Zeller, 1965, 1978; Hayes and Raup, 1968; Drewes, 1971, 1975, 1991; Drewes and Thorman, 1980)
Age: Early Permian
Occurrence/unit thickness: Peloncillo Mountains? (thickness is unknown due to faulting); southwestern Big Hatchet; Tres Hermanas Mountains; Animas Mountains (about 458 m thick). Large clasts of Epitaph are found in Tertiary tuffs in the Animas Mountains. Isopachs of the Yeso and Epitaph in southern N. Mex., Mesozoic eroded edge, and the intra-Permian eroded edge, are given in Kottlowski (1963, fig. 15). Variable thickness.
Type locality: dip slope of Colina Ridge, west of Epitaph Gulch, 1.5 km south of Horquilla Peak in Tombstone Hills, Cochise Co. AZ (Gilluly and others, 1954)
Correlation: may be interbedded with Colina Limestone, northern Animas Mountains.
Lithologies: Dolomite, cherty; dolomitic limestone, siltstone, marlstone. Lenticular gypsum.
Fossils: Gastropods, echinoid spines.
Depositional environment:
Stratigraphic relations to underlying units or predecessors: Interbedded with Colina Limestone, Animas and Big Hatchet Mountains; faulted in Peloncillo Mountains
Stratigraphic relations to overlying units or successive rocks: Faulted

Commodities: Localized gypsum occurrences in the Mimbres Resource Area.

Escabrosa Group (Ransome, 1904; Armstrong, 1962, 1970; Zeller, 1965; Soulé, 1972; Armstrong and others, 1980; Drewes and Thorman, 1980; Thorman and Drewes, 1981)
Age: Early and Late Mississippian (Osagean, Tournaisian, Visean and Meramecian). The Escabrosa is nearly a complete Mississippian section (there are no significant hiatuses that occur within the unit).
Subunit name (Age): In southwestern New Mexico the Escabrosa has been subdivided by Armstrong (1962) into the lower Keating Formation and upper Hachita Formation. The Keating has been subdivided into the lower Bugle Member and upper Witch Member (Armstrong and Mamet, 1978). In the Big Hatchet Mountains, Drewes (1991) mapped the Hachita Member, Keating Member, White unit, and Black unit.
Occurrence/thickness: Occurrence/unit thickness: Crops out in the Animas Mountains (at least 183 m thick), Big Hatchet Mountains (385 m thick), Cedar Mountains (more than 310 m thick), Klondike Hills (Keating and Hachita Formations at least 92 m thick), Peloncillo Mountains (as much as 153 m thick), Sierra Rica, Apache Hills, Tres Hermanas Mountains (at least 110 m thick, base not exposed), and in other areas of Hidalgo County. Northward from the Robledo Mountains, Mississippian units are erosionally thinned in early Pennsylvanian time. Thickest in Pedregosa Basin.
Type locality: none. Named from Escabrosa Ridge, Mule Mountains, Cochise County, AZ (Ransome, 1904)
Correlation:
Lithologies: Coarse-grained bioclastic carbonate rocks. In the Animas Mountains, the Escabrosa has basal, brecciated, coarse-grained dolomite unit, probably of secondary origin.
Fossils:
Stratigraphic relations to underlying units or predecessors: Unconformable on Devonian rocks
Stratigraphic relations to overlying units or successive rocks: Grades into Paradise Formation
Commodities: Tres Hermanas District: carbonate-hosted Pb-Zn deposits. May be an important source of high-calcium limestone (Kottlowski, 1962). Rincon District: replacement deposits along faults. Laramide skarn deposits in the Tres Hermanas district.

Fall Canyon Tuff (Ratté, 1981; Ratté and others, 1979)
Age: Tertiary, Oligocene (Ratté, 1981; Marvin and others, 1987)
Occurrence/unit thickness: Black Range
Type locality: W 1/2, sec 23, T. 13 S., R. 17 W., Shelley Peak quad, Grant Co. Named for Fall Canyon, Shelley Peak quad, Catron Co. (Ratté, 1981)
Correlation:
Lithology:
Fossils:
Depositional environment: welded ash-flow tuff; pre-caldera rocks of the Gila Cliff Dwellings and Bursum calderas
Stratigraphic relations to underlying rocks or predecessors:
Stratigraphic relations to overlying rocks or successors:
Commodities:

Fierro Limestone (Paige, 1916) Abandoned
Age: Mississippian, Pennsylvanian, and Permian
Occurrence/unit thickness: Silver City quadrangle

Type locality: None. Section measured in a gulch west of Silver City and named for the town of Fierro
Correlation: Lake Valley Limestone
Lithology:
Fossils:
Depositional environment:
Stratigraphic relations to underlying rocks or predecessors:
Stratigraphic relations to overlying rocks or successors:
Commodities:

Fusselman Dolomite (Richardson, 1908, 1909; Paige, 1916; Nelson, 1940; Kelley and Silver, 1952; Pray, 1953; Balk, 1961; Kottlowski, 1963; Greenwood and others, 1977; Thorman and Drewes, 1981; Seager, 1981; Cunningham, 1974; Poole and others, 199–)
Age: Early and Middle Silurian
Occurrence/thickness: Bishop Cap, Black Range, Cookes Range and Fluorite Ridge (84 m thick), Cedar Mountains area, East Potrillo, Florida Mountains (up to 450 m thick), northern Franklin Mountains (185 m thick), Klondike Hills, Organ-San Andres Mountains, Pinos Altos Range/Silver City Range (30-915 m thick), Robledo Mountains (76 m thick), San Diego Mountains/Tonuco uplift area (46 m thick) (Seager, 1975), Tres Hermanas Mountains (several hundred m thick), Victorio Mountains (10-270 m thick). In the northern Selden Hills (at least 46 m thick); may constitute a slide block (Seager, 1975). In the central Peloncillo Mountains, Big Hatchet Mountains, and the Animas Mountains, the Silurian is not represented. It is not present west of the Klondike hills on the surface, but occurs in the subsurface as far west as The Saltys (Clemons and Mack, 1988). Isopachs of the Fusselman dolomite in southwestern N. Mex., the Burro Uplift, and the Devonian eroded edge, are given in Kottlowski (1963, fig. 5).
Type locality: None. Name derived from Fusselman Canyon, southern Franklin Mountains near El Paso, Tex. (Richardson, 1908; Kelley and Silver, 1952)
Correlation:
Lithologies: Massive dolomite and limestone; karstic, vuggy, and cavernous. Unit may contain lenses of chert; locally sucrosic. In Tres Hermanas Mountains, consists of marbelized dolomite/limestone with local lenses of calcarenite and breccia.
Fossils: Brachiopods, gastropods, sponges, corals, crinoid fragments.
Depositional environment: Shallow marine. In the Silver City area, the contact with the overlying Percha Shale is described as a paleokarst, containing paleosols, cave fillings, and breccias (Young, 1994).
Stratigraphic relations to underlying units or predecessors: Faulted in Tres Hermanas Mountains and the Selden Hills. Faulted in the San Diego Mountain region. Sharply unconformable on Montoya Group in Organ Mountains.
Stratigraphic relations to overlying units or successive rocks: Unconformable with Canutillo in the Organ and San Andres Mountains; faulted in Tres Hermanas Mountains and the Selden Hills. A karstic contact with overlying Percha Shale in the vicinity of Silver City, including cave fillings, paleosols, and breccias, was formed during uplift and exposure prior to the Late Devonian (Young, 1994).
Commodities: In the Tres Hermanas Mountains, the unit consists of marbelized dolomite and limestone. Fusselman is host to metals (lead, silver, and gold in carbonate-hosted Pb-Zn replacement and vein deposits) in the Cookes Range and Florida Mountains areas, where silicification accompanied ore deposition. In the northern Franklin Mountains District and Bear Mountains District, vein and replacement zones commonly contain barite, fluorite,

and limonite, calcite, and quartz. Argentiferous galena has been produced from the northern Franklin Mountains District. In the Organ and San Andres Mountains, the uppermost Fusselman is host to replacement barite-fluorite and base- and precious-metal deposits at the Mountain Chief Mine, Black Mountain District, and in the San Andres Canyon District. In the Rincon District, sedimentary hydrothermal barite-fluorite deposits are present. Hydrothermal mineralization occurred at the karstic contact with the Percha Shale in Laramide time in the Silver City area (ee Chloride Flat district). Adjacent to the Organ batholith, thermally metamorphosed to marble; may contain tremolite, garnet, serpentine. Silver-bearing vein and replacement deposits, Georgetown district. Silver deposits in Lone Mountain district. Manganiferous iron ore in the Chloride district (Boston Hill and Chloride Flat mines) is an intimate mixture of hematite and pyrolusite.

Gila Conglomerate (Gilbert, 1875, Hedlund, 1978, 1979; Ratté, 1989; Ratté and others, 199–)

Age: Tertiary (Oligocene?, Miocene, Pliocene, Quaternary, Pleistocene) Basalt flows dated near the base and top range from 20 m.y. to 6 m.y., respectively; reported in Ratté and others, 1979) (Pleistocene, Pliocene, and Miocene; Brooks and Ratté, 1985). Fossil evidence, correlation of ash beds, and K-Ar-dating of interbedded basalt flows indicates that the deposits range in age from Miocene to mid-Pleistocene.

Occurrence/unit thickness: In drainages of Gila and Mimbres Rivers (tens of m thick). Mimbres Valley, southern Black Range, and Cookes Range (variable, but as much as 458 m thick); Tres Hermanas Mountains; Black Mountains/Knight Peak area; Tillie Hall Peak quadrangle (Hedlund, 1993); Knight Canyon, 430 m thick (Hedlund, 1978, Burro Peak quad); 250 m thick in Werney Hill quad, southeast of Big Burro Mountains (Hedlund, 1978); 300 m thick, Soldiers Farewell Hill quad; in valleys of the Alum Mountain area; San Francisco Canyon area; Caprock Mountain mining district. Valleys in Burro Mountains area.

Type locality: None. Named for expsures along the gorges of the upper Gila River and its tributaries, AZ and NM (Gilberg, 1875)

Correlation: Santa Fe Group, Rio Grande Valley; Mimbres Conglomerate (Hernon and others, 1953) and "semiconsolidated gravel deposits of Mimbres Valley" (Jones and others, 1967). Rocks of this series were deposited during development of the Rio Grande rift, and are widespread within and adjacent to the rift. Gila Conglomerate and Santa Fe Group are equivalent units that have been distinguished according to their occurrence by drainage basin. Santa Fe Group is restricted to all areas of the Rio Grande drainage and to closed basins east of the Rio Grande. Santa Fe Group was deposited in basins within and adjacent to the rift, and shows evidence of the entrenchment of the Rio Grande river. Gila Conglomerate is restricted to all areas where surface drainage is into the Colorado River and its tributaries, or to closed basins west of the Rio Grande River above Hatch, and west of Sierra de las Uvas and the West Potrillo Mountains.

Lithologies: Poorly stratified conglomerate, derived mostly from volcanic deposits in the Black Range; interbedded basalt. Sedimentary and volcanic complexes, including rhyolite dikes and sills, fanglomerates, and tuffaceous sandstones and conglomerates.

Fossils: freshwater brine shrimp

Depositional environment: Fanglomerate and associated environments

Stratigraphic relations to underlying units or predecessors: upper part of Bearwallow Mountain Formation

Stratigraphic relations to overlying units or successive rocks: Quaternary deposits

Commodities: Gypsum, travertine, pumice, diatomite, caliche, sand and gravel, and clay. Fluorite, meershaum, and epithermal manganese veins in Caprock and Alum Mountain districts. Placer gold deposits locally. Placer magnetic iron, Lone Mountain district.

Locally coated with copper-bearing minerals in the northern Big Burro Mountains. Hot springs common; evidence of hot spring alteration obvious between Silver City and Gila Cliff Dwellings National Monument. Geothermal waters are used in greenhouse industries in southwestern NM. Zeolites (lacustrine facies) in Buckhorn deposit, Grant County, at Gila deposit tuff

Gila Flat flows (Ratté and others, 1979)
Age: 29.6 ±1.1-29.3±1.1 m.y. (Ratté and others, 1979)
Occurrence/unit thickness: Alum Mountain mining district; surrounds the Alum Mountains volcanic complex
Type locality:
Correlation:
Lithologies: latite, andesite
Fossils:
Depositional environment: lava flows
Stratigraphic relations to underlying units or predecessors:
Stratigraphic relations to overlying units or successive rocks:
Commodities:

Gillespie Tuff (Zeller, 1962; Zeller and Alper, 1965; Brooks and others, 1989)
Age: Tertiary, Oligocene; 32.1+0.7; 32.9+0.7; Elston and Erb, 1977; Deal and others, 1978; Erb, 1979
Occurrence/unit thickness: Animas Mountains; Alamo-Hueco Mountains (up to 220 m thick); southern Peloncillo Mountains. Source may be the Cowboy Rim caldera.
Type locality: none. Named for exposures on Gillespie Mountain, Animas Mountains, sec. 33, T. 30 S., R. 18 W., Walnut Wells quad, Hidalgo Co (Zeller and Alper, 1965)
Correlation:
Lithologies: Rhyolite to quartz latite, abundant pumice
Fossils:
Depositional environment: Ash-flow tuff; probably fill of and outflow from the Cowboy Rim caldera (Erb, 1979)
Stratigraphic relations to underlying units or predecessors: Conformable locally on tuff of Gray Ranch and with the Oak Creek tuff, Alamo-Hueco Mountains.
Stratigraphic relations to overlying units or successive rocks: Conformable with basaltic andesite flows, Alamo-Hueco Mountains.
Commodities: Pumice (in layers up to 15 m thick in Alamo-Hueco Mountains); radioactive veins of opal and quartz 2-5 cm thick (Alamo-Hueco Mountains); Antelope Wells-Dog Mountains mining district

Glance Conglomerate (Bisbee Group) (Ransome, 1904; Hayes, 1970; Drewes and Thorman, 1980, Drewes, 1981, 1986, 1991; Thorman and Drewes, 1981)
Age: Early Cretaceous (Neocomian and early Aptian) Basal unit of the Bisbee Group.
Occurrence/unit thickness: Animas Mountains; Big Hatchet; Sierra Rica and Apache Hills; Cedar Mountains area
Type locality: none. Named for Glance station in NE 1/4 NW 1/4, sec 4, T. 24 S., R. 25 E., Cochise Co. AZ (Ransome, 1904)
Correlation:
Lithology:
Fossils:

Depositional environment:
Stratigraphic relations to underlying rocks or precursors:
Stratigraphic relations to overlying rocks or successors:
Commodities:

Graham Well tuff (Deal and others, 1978; Elston and others, 1983; Elston, 1994)
Age:
Occurrence/unit thickness: Rocks of the Muir caldera, Pyramid Mountains
Type locality:
Correlation:
Lithologies: Quartz latite
Fossils:
Depositional environment: Volcanic tuffs, flows, megabreccia
Stratigraphic relations to underlying rocks or precursors:
Stratigraphic relations to overlying rocks or successors:
Commodities:

Granite Gap granite (Gillerman, 1958; Armstrong and others, 1979; McLemore and others, 1995)
Age: Tertiary or Cretaceous; emplaced 33.2 m.y. ago (McLemore and others, 1995)
Occurrence: central Peloncillo Mountains
Type locality: none. Named for Granite Gap, sec. 31, T 25 S., R. 20 W. Hidalgo Co.
Correlation:
Lithologies: granite
Fossils:
Depositional environment: pluton approximately 8 km^2 in outcrop area
Stratigraphic relations to underlying rocks or precursors: intrudes Paleozoic and Mesozoic sedimentary rocks in vicinity of Granite Gap, Peloncillo Mountains
Stratigraphic relations to overlying rocks or successors:
Commodities:

Granite Peak granite (Seager, 1981; Seager and McCurry, 1988)
Age: Tertiary
Occurrence/thickness: Organ Mountains (Organ batholith)
Type locality: none.
Correlation:
Lithology: quartz monzonite
Fossils:
Depositional environment: Intrusive unit of the Organ batholith complex
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities: Skarn and carbonate-hosted Pb-An replacement deposits, Granite Gap mining district

Gray Ranch tuff (Erb, 1979)
Age:
Occurrence/thickness: Animas Mountains, Alamo-Hueco Mountains
Type locality: Black Canyon, Animas Mountains
Correlation:

Lithologies: rhyolite, crystal rich
Fossils:
Depositional environment: ash-flow tuff
Stratigraphic relations to underlying units or predecessors: Conformable with Oak Creek tuff
Stratigraphic relations to overlying units or sucessors:
Commodities:

Guadalupe Canyon tuff (Erb???)
Age:
Occurrence/thickness: Peloncillo (Geronimo Trail caldera)
Type locality:
Correlation:
Lithologies:
Fossils:
Depositional environment:
Stratigraphic relations to underlying units or predecessors:
Stratigraphic relations to overlying units or sucessors:
Commodities:

Hachita Formation (Escabrosa Limestone) Balk, 1961; Armstrong, 1962, 1970; Zeller, 1965 (unit not used); Armstrong and others, 1978, 1980; Drewes and Thorman, 1980 (unit not used); Drewes, 1991)
Age: Early and Late Mississippian
Occurrence/unit thickness: Klondike Hills (92 m thick); Animas Mountains, Peloncillo Mountains (44 m thick); Big Hatchet Mountains (271 m thick).
Type locality: South end of Blue Mountain, Chiricahua Mountains, Cochise Co., Az, in S1/2 sec 20, T. 16 S., R. 30 E. (Armstrong, 1962)
Correlation: Shelf equvalent of the basinal Rancheria Formation to the east (Clemons and Mack, 1988).
Lithologies: Limestone. Chert occurs locally
Fossils: Lower part is composed of crinoid-fragment hash (crinoidal clastic limestone) underlying a thick-bedded, crinoid-, brachiopod-, and bryozoan-bearing clastic limestone.
Depositional environment:
Stratigraphic relations to underlying units or predecessors: Gradational with the underlying Keating Formation in southwestern New Mexico.
Stratigraphic relations to overlying units or successive rocks: Gradational with the overlying Paradise Formation in southwestern New Mexico.
Commodities: silica, copper, lead mineralization, and jasperoids (Klondike Hills)

Hayner Ranch Formation, Santa Fe Group (Seager and Clemons, 1975; Walker, 1986)
Age: early to middle Miocene
Occurrence/thickness: Cedar Hills-Selden Hills area (580 m thick); San Diego Mountain/Tonuco Uplift (951 m thick), Rincon Hills
Type locality:
Correlation:
Lithology: sandstone (brick red), conglomeratic sandstone, conglomerate. May be silicified.
Fossils:

Depositional environment: Intertonguing piedmont-slope and basin-floor deposits that accumulated in a local, rapidly subsiding, basin during the early stages of rifting (Seager, 1975; Walker and Mack, 1985)
Stratigraphic relations to underlying rocks or predecessor(s): conformable with an unnamed "transitional unit"
Stratigraphic relations to overlying rocks or successor(s): local angular unconformity with Rincon Valley Formation and younger deposits
Commodities: Tonuco Mountain District: Fluorite-barite veins.

Hell-to-Finish Formation (Zeller, 1958, 1965, 1970, 1975; Zeller and Alper, 1965; Hayes, 1970; Drewes, 1991)
Age: Early Cretaceous
Occurrence/thickness: typically tens of feet thick and poorly exposed in Animas Mountains, but near Winkler Anticline, up to 235 m thick; Big Hatchet Mountains, Glance Conglomerate (1-53 m thick), Hell-to-Finish Formation (397 m thick); Little Hatchet Mountains (as much as 1,830 m thick), Peloncillo Mountains (at least 92 m thick), East Potrillo Mountains (207 m thick).
Type locality: southern Big Hatchet Mountains, near Hell-to-Finish Tank, NE $^1/_4$, NW $^1/_4$, sec 11, T. 32 S., R. 15 W., Hidalgo Co. (Zeller, 1965)
Correlation: Mapped by Drewes (1986) as the Cintura Formation and an undivided upper unit, both shale, siltstone, and sandstone units, northern Animas Mountains. The lower Glance Conglomerate and the overlying Hell-to-Finish were differentiated in the Big Hatchet Mountains. The basal conglomerate of the Glance Conglomerate mapped by Zeller (1965) is included in the Hell-to-Finish by Drewes (1991).
Lithology: Arkose and shale; subgraywacke sandstone, conglomerate, limestone, dolostone, silty lime mudstone. Red and gray shale, red siltstone, limestone-cobble conglomerate, arkose, and sandy limestone. Recrystallized near Granite Peak, Peloncillo Mountains; metamorphosed in Little Hatchet Mountains (Zeller, 1970).
Fossils: Fossilized wood, shell fragments.
Depositional environment: Almost entirely nonmarine in Peloncillo, Animas, Big Hatchet and Little Hatchet Mountains; mostly marine (basal part nonmarine) in East Potrillo Mountains (Clemons and Mack, 1988).
Stratigraphic relations to underlying rocks or predecessor(s): Unconformable on the Earp Formation and Colina Limestone. Glance is unconformable on Permian rocks, Big Hatchet Mountains. Base is covered or cut out by a thrust fault in the Little Hatchet Mountains (Zeller, 1970)
Stratigraphic relations to overlying rocks or successor(s): Glance in fault contact with Hell-to-Finish Formation, Big Hatchet Mountains, according to Drewes (1986). Conformable or gradational with U-Bar Formation in Big Hatchet and Little Hatchet Mountains, according to Zeller (1965; 1970) and Weise (1982).
Commodities: gypsum in Big Hatchet Mountains district; copper-garnet skarn deposit at Copper Dick mine, Sylvanite district. Localized gypsum occurrences.

Hells Hole, rhyolite of (Ratté and Hedlund, 1981; Ratté and Brooks, 1983)
Age: 27 m.y. (zircon fission-track; Ratté and Brooks, 1983)
Occurrence/thickness: Hells Hole area north of Summit Mountains; eastern Big Lue Mountains area (400 m thick, exposed over 75 km^2)
Type locality:
Correlation:

Lithology: rhyolite
Fossils:
Depositional environment:
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s): andesitic lavas of Pine Cienega Peak
Commodities:

Helms Formation (Nelson, 1940; Laudon and Bowsher, 1949; Harbour, 1971; Lane, 1974; Seager, 1981)
Age: Late Mississippian (Chesterian)
Occurrence/thickness: Southern Organ Mountains, Bishop Cap (40 m thick); northern Franklin Mountains (127 m thick). Isopachs of the Paradise and Helms in southern N. Mex., the Jarilla Uplift(?), and the Burro Uplift, are given in Kottlowski (1963, fig. 8).
Type locality: none
Correlation:
Lithology: Soft, calcareous shale unit. Crinoidal, oolitic, and marly limestone. Contains a quartzite lens (6 m thick).
Fossils: Brachiopods, gastropods, ostracods, and bryozoa; crinoidal limestone, massive fossiliferous limestone. Quartzite with plant impressions at top, northern Franklin Mountains.
Depositional environment: Nearshore marine and terrigenous origins.
Stratigraphic relations to underlying units or predecessors: Interfingers with underlying Rancheria Formation
Stratigraphic relations to overlying units or successive rocks: Disconformable with La Tuna Formation at Bishops Cap.
Commodities:

Hickory Creek quartz latite (Erb, 1979)
Age:
Occurrence/thickness:Peloncillo (Geronimo Trail caldera)
Type locality:
Correlation:
Lithology:
Fossils:
Depositional environment:
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities:

Hidalgo Volcanics Bisbee Group (Lasky, 1938, 1947; Hayes, 1970; Marvin and others, 1978; Richard and Courtright, 1960)
Age: Late Cretaceous; Tertiary (Paleocene, Eocene, Oligocene); 71 m.y. ($^{40}Ar/^{39}Ar$, hornblende; Lawton and others, 1993)
Occurrence/unit thickness: Southwest New Mexico. Brockman Hills, Little Hatchet Mountains (0-1,678 m thick). Missing in Coyote and Brockman Hills just north of Little Hatchet Mountains.
Type locality: none. Named for Hidalgo Co. (Lasky, 1938)
Lithology: Mostly basaltic and andesitic volcanics; in upper part, locally contains limestone, shale, and gritty or conglomeratic layers. Brecciated flows in the Little Hatchet Mountains.

Fossils: Fossil wood *Salix* (Little Hatchet Mountains)
Depositional environment: Volcanic flows, sedimentary rocks
Stratigraphic relations to underlying units or predecessors: Unconformably on older formations (Little Hatchet Mountains; Zeller, 1970)
Stratigraphic relations to overlying units or successive rocks: disconformable with Howell Ridge formation. Upper part truncated by thrust faults (Little Hatchet Mountains)
Commodities:

Hog Canyon, breccia of (Erb, 1979)
Age:
Occurrence/thickness: Peloncillo (Geronimo Trail caldera)
Type locality:
Correlation:
Lithology:
Fossils:
Depositional environment:
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities:

Hog Ranch, volcanics of (Erb, 1979)
Age:
Occurrence/thickness: Peloncillo (Geronimo Trail caldera)
Type locality:
Correlation:
Lithology:
Fossils:
Depositional environment:
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities:

Holtcamp Canyon andesite ((Deal and others, 1978; Elston and others, 1983)
Age:
Occurrence/thickness: Pyramid Mountains
Type locality:
Correlation:
Lithology:
Fossils:
Depositional environment: volcanic
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities: host for volcanic-epithermal vein deposits in the Silver Tree and Allen mines, Muir mining district, Pyramid Mountains.

Horquilla Limestone, lowermost Naco Group (Gilluly, Cooper, and Williams, 1954; Zeller, 1960, 1962, 1965, 1970; Drewes and Thorman, 1980; Drewes, 1991)
Age: Early, Middle and Late Pennsylvanian; Early Permian

Occurrence/unit thickness: Klondike, Coyote, and Brockman Hills, as much as 150 m thick. Animas Mountains (as much as 519 m thick), exposed in the core of the Winkler Anticline; Peloncillo Mountains (473-m-thick); Cedar Mountains area (only a few tens of meters); Pyramid Mountains (tentative identification); Big Hatchet Mountains and Sierra Rica/Apache Hills (990-1052 m thick). Marbleized Horquilla in isolated hills, west side of Granite Pass, Little Hatchet Mountains, Horquilla is mapped based on fossiliferous chert nodules interbedded in the marble. Neither the Horquilla nor any other Pennsylvanian sequences are recognized in the Florida Mountains. Described from petroleum exploration wells into intermontane basins near the Big Hatchet Mountains; (in Humble No. 1BA State well, located southwest of the Big Hatchet Mountains), shelf sediments are 1,098 m thick and basinal sediments are as much as 1,403 m thick. Isopachs of the Abo, Earp, and Hueco-Horquilla facies in southern N. Mex., the Mesozoic eroded edge, and the Burro Uplift, are given in Kottlowski (1963, fig. 9).

Type locality: On eastern spur of Horquilla Peak in the Tombstone Hills, Cochise Co. AZ (Gilluly and others, 1954)

Correlation:

Lithology: Crystalline limestone, calarenite, silty limestone; rare shale and sandstone. Irregular nodules and lenses of chert. Commonly dolomitized. Horquilla in the Animas Mountains contains massive limestone replaced with novaculite-like chert that has been highly fractured and locally faulted; some of the 1-m-wide veins in the massive limestones contain fluorite and associated rare crystals of pale amethyst and yellow quartz (citrine). In the Klondike Hills, basal Horquilla is composed of silica-cemented quartz sandstone.

Fossils: Abundantly fossiliferous, containing massive beds of crinoidal limestone in its lower half; fusulinids are locally plentiful. Other fossils include corals, sponges, brachiopods, and bryozoans. In the Peloncillo Mountains, the Horquilla is pelloid-echinoderm-brachiopod-foraminiferal clastic limestone. In the Klondike Hills, the basal Horquilla contains plant molds and impressions.

Depositional environment: In the northern, eastern, and western parts of Hidalgo county, the clastic rocks are marine and nonmarine. Massive, shallow-water carbonates include 366 m-thick reefs (Big Hatchet Peak).

Stratigraphic relations to underlying units or predecessors: Faulted locally and disconformable on Paradise in Peloncillo Mountains

Stratigraphic relations to overlying units or successive rocks: Gradational into Earp in Peloncillo Mountains

Commodities: marble. Animas Mountains, Gillespie district vein deposits; azurite and malachite occur on the dump; linnearite was found in a vug from a prospect pit. Fluorspar deposits at Winkler Anticline occur as scattered pods and breccia cement in irregular fluorite-jasperoid replacement mantos. Rincon District: carbonate-hosted lead-zinc, volcanic-epithermal, and carbonate-hosted manganese deposits. High calcium limestone may be present locally. Marble occurs on west side of Granite Pass in Little Hatchet Mountains. Lead-silver-zinc oxide and sulfide minerals occur with calcite and limonite-manganese-stained gouge along bedding planes and faults in Horquilla Limestone, Big Hatchet Mountains district. Winkler fluorspar deposts are hosted in the Horquilla Limestone, Gillespie district. Pb-Zn replacement deposits, Rincon mine. Tungsten skarn deposits, Sylvanite district. Sulfide replacement deposits at Carbonate Hill mine and copper skarn deposits at Johnny Bull mine, McGhee Peak district.

Howells Ridge Formation (Bisbee Group)(Lasky, 1938; Zeller, 1970; Hayes, 1970)

Age: Early Cretaceous

Occurrence/thickness: Little Hatchet Mountains
Type locality: None designated. Named for ridge in the Little Hatchet Mountains.
Correlation:
Lithology:
Fossils:
Depositional environment:
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities: molybdenum-tungsten-bearing skarn occurrence in a garnetifeous zone, Cactus Group claims, Sylvanite district.

Hueco Group (Richardson, 1904; Dunham, 1935; Nelson, 1940; Bogart, 1953; Bachman and Hayes 1958; Kottlowski, 1963; Kelley and Matheny, 1983; Kohn and ??, 1990)
Age: Early Permian; Wolfcampian and Leonardian
Occurrence/unit thickness: Doña Ana Mountains (523 m thick); Florida Mountains (partial thickness totals 131 m); northern Franklin Mountains (824 m thick); Mimbres Basin (as much as 107 m thick); central Organ Mountains near Modoc mine (580 m thick); Robledo Mountains (523 m thick, including the Abo clastic tongue); southern San Andres Mountains (excluding Abo red beds, about 413 m thick near Love Ranch); San Diego Mountain/Tonuco uplift area, Tres Hermanas Mountains (at least 160 m thick); possibly occurs in the East Potrillo Mountains (61 m thick); Bishop Cap (subsurface). Isopachs of the Abo, Earp, and Hueco-Horquilla facies in southern N. Mex., the Mesozoic eroded edge, and the Burro Uplift, are given in Kottlowski (1963, fig. 9).
Type locality: None. Named from Hueco Mountains, Hudspeth Co. TX where unit is exposed (Richardson, 1904)
Correlated with: Most Hueco outcrops are questioned. Intertongue vertically and laterally with nonmarine sediments of the Abo Formation and Lobo Formation. Earlier called the Gym limestone by Darton (1916), as described by Bogart (1953), and now abandoned. (see also Abo Formation)
Lithologies: Limestone and marly siltstone; locally dolomitic, conglomeratic, cherty, metamorphosed, oolitic, biostromal. Cherty fossiliferous limestone, argillaceous limestone, silty calcarenite, fossiliferous shale. Sandstone and chert-pebble conglomerate occurs in places.
Fossils: Brachiopods, crinoids, gastropods, corals, fusulinids, ostracods; Abo–Hueco is host to a dinosaur tracksite in Robledo Mountains
Depositional environment: Basinal deposits of the marine Orogrande basin. In Tres Hermanas Mountains, records the transition between the Pedregosa and Orogrande Basins.
Stratigraphic relations to underlying units or predecessors: Conformable on Panther Seep Formation, northern Franklin Mountains. In Tres Hermanas Mountains, a 9-m thick-tongue of clastic sediment [called the "Abo(?) tongue"] overlies fossiliferous limestone. Northward from Robledo Mountains, the intertongued Abo-Hueco grades into an Abo red-bed facies with no limestone. In the southern San Andres Mountains, the intertonguing Hueco and Abo are 435 m thick. Intertongued units are mapped in the Doña Ana Mountains. In Florida Mountains, basal contact is faulted or unconformable on Mississippian strata (Lake Valley Limestone). See Bursum Formation.
Stratigraphic relations to overlying units or successive rocks: In Florida Mountains, unconformable with Cretaceous-Tertiary(?) Lobo Formation rocks; faulted in the Tres Hermanas Mountains. Grades upwards into the Abo in the San Andres Mountains. Hueco is truncated by the Laramide uplift in the Organ Mountains, but is present along the

western edge of the uplift in the western Organ Mountains where it is overlain by Tertiary conglomerates and volcanic rocks.

Commodities: Potrillo Mountains District: Sedimentary-hydrothermal barite-fluorite deposits; travertine deposits localized along faults; marbleized limestone; localized high-calcium limestone and replacement barite. Northern Franklin Mountains District: gypsum and limestone (high-calcium type). Robledo Mountains, Iron Hill District: Iron deposits; high-calcium limestone. Potrillo Mountains marble occurrence.

Johnny Bull Sandstone (Bisbee Group)(Gillerman, 1958; Hayes, 1970; Armstrong and others, 1978; Drewes, 1986)

Age: Early Cretaceous

Occurrence/thickness: The uppermost member of the Bisbee Group in the central Peloncillo Mountains.

Type locality: Near Johnny Bull Mine, sec. 4, T. 25 S., R. 21 W., Hidalgo County (Gillerman, 1958)

Correlation:

Lithology:

Fossils:

Depositional environment:

Stratigraphic relations to underlying rocks or predecessor(s):

Stratigraphic relations to overlying rocks or successor(s):

Commodities:

Jose Placencia Canyon rhyolite(Deal and Elston, 1983)

Age: Tertiary

Occurrence/thickness: rocks of the Muir caldera, Pyramid Mountains; Tres Hermanas

Type locality:

Correlation:

Lithology: Four volcanic units are delineated on map. Mostly rhyolite and rhyodacite. Intensely argillized and pyritized in Pyramid Mountains.

Fossils:

Depositional environment: Volcanic flows and tuffs, dikes

Stratigraphic relations to underlying rocks or predecessor(s):

Stratigraphic relations to overlying rocks or successor(s):

Commodities:

Keating Formation (Escabrosa Group) (Armstrong, 1962; Armstrong and Mamet, 1978; Drewes, 1991, Armstrong and others, 1978; Drewes and Thorman, 1980)

Age: Early Mississippian, Tournaisian

Occurrence/thickness: Klondike Hills (214 m thick); Big Hatchet Mountains (180 m thick, includes Black and White units); Peloncillo Mountains (111 m thick), Animas Mountains.

Type locality: Section: Sec. 20, T. 16 S., R. 30 E., Cochise Co. AZ on southeast side of Blue Mountain, Chiricahua Mountains (Armstrong, 1962; 1970)

Correlation: Subdivided by Armstrong and Mamet (1978) into the lower Bugle Member and the upper Witch Member. Includes the Black and White units of Drewes (1991) in the Big Hatchet Mountains.

Lithology: Calcareous shale, silt, sandstone, cherty limestone, thin-bedded and limy mudstone, dolomite, and lenticular and nodular chert. In the Klondike Hills, the upper part has a higher organic component (Greenwood and others, 1970).

Fossils: Bryozoan, crinoid, echinoderm, brachiopods, and coral fragments in limestone, trace fossils, and occasional oolite beds.
Depositional environment:
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s): In the Peloncillo Mountains, disconformably overlies the Percha Shale.
Commodities:

Kneeling Nun Tuff, Datil Formation (Jicha, 1954; Hernon and others, 1964; Pratt, 1967; Ratté and others, 1991; Jones and others, 1970 Ericksen and others, 1970)
Age: Tertiary, Oligocene. K-Ar age determination; a basal tuff unit near the Caballo Reservoir; 33.6 m.y. (Oligocene)(Burke and others, 1963; 33.4 + 1.0 m.y., Elston and others, 1975; Hedlund 1978, Burro Peak quad).
Occurrence/thickness: Widely exposed in the Southern and central Black Range and Cobre Mountains, especially in the Santa Rita mining district and Good Sight Mountains. Cookes Range (61 m thick); Black Range/Mimbres Mountains (at least 397 m thick, and may be more than 1,006 m thick); Good Sight Mountains (0-31 m thick). Pinos Altos Range/Silver City Range (120-180 m thick); Mimbres Range (60-120 m thick); Soldiers Farewell Hill quad, 225 m thick; Werney HIll quad, 145 m thick (Hedlund, 1978). May be present in the subsurface as far north as Uvas Valley (Clemons, 1979). In the Santa Rita mining district, the Kneeling Nun makes up a large anticline interpreted to be a resurgent dome (Ericksen and others, 1970); shows evidence of at least two cooling units. Kuellmer (1953) recognized a vent for the source of the ash flow tuffs on the west side of the Black Range and Elston and others (1975) called this the Emory caldera. Outflow sheets generally less than 137 m thick. Jointing prominent. In C-Bar Ranch quad (Hedlund, 1978), unit is up to 76 m thick.
Type locality: None. Named for Kneeling Nun, a landmark in the Santa Rita area, Grant Co. (Jicha, 1954)
Correlation:
Lithology: Quartz latite, rhyodacite, to rhyolite
Fossils:
Depositional environment: Massive, welded and cemented ash flows representing many cooling units. Composite flow unit of rhyolitic to quartz latitic flows at the base and latitic flows at the top.
Stratigraphic relations to underlying rocks or predecessor(s): Unconformable. Gradational with Sugarlump Tuff east of Mimbres. Deposited on Rubio Peak Formation in Good Sight Mountains.
Stratigraphic relations to overlying rocks or successor(s): Unconformable. Overlain by the Mimbres Peak Formation east of Mimbres. Intruded and overlain by Tenaga Canyon formation in Good Sight Mountains. Variable in Pinos Altos Range/Silver City Range; overlying rocks include basaltic andesite flows, indurated rhyolite tuff, pitchstone flow, and sandstone that are probably part of the Mimbres Peak Formation.
Commodities: perlite, pumice, clays, zeolites

Knight's Peak series of Gillerman (1970)
Age:
Occurrence/thickness: Big Burro
Type locality:
Correlation:

Lithology:
Fossils:
Depositional environment:
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities:

La Tuna Member (Magdalena Group) (Nelson, 1940; Harbour, 1972; Seager, 1981)
Age: Early Pennsylvanian, Morrowan
Occurrence/thickness: Bishop Cap; Franklin Mountains (up to 107 m thick); Organ/San Andres Mountains.
Type locality: none. Named for the town of La Tuna on the Santa Fe RR at the TX-NM boundary, El Paso Co. TX. Section measured opposite Vinton, El Paso Co (Nelson, 1940).
Correlation:
Lithology: Cherty micrite, Organ Mountains; dense crinoidal limestone with lenses of aphanitic chert, thin lenses of shale near the top, Franklin Mountains. Basal unit is massive; shale content increases upward. Authigenic quartz crystals.
Fossils: Abundant silicified corals, brachiopods, crinoids, mollusks, bryozoans, petrified wood
Depositional environment: Nearshore marine
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s): Grades into Berino Formation
Commodities:

Lake Valley Limestone (Gordon, 1907; Armstrong, Mamet, and Repetski, 1980; Laudon and Bowsher, 1949; Jicha, 1954; Kottlowski, 1963; Cunningham, 1974; Flih, 1976; Seager, 1981)
Age: Early Mississippian, Kinderhookian and Osagean
Occurrence/thickness: Bishop Cap (55 m thick); Black Range and Lake Valley area (52-69 m thick); Cobre Uplift (92-120 m thick); Cookes Range (119 m thick); Florida Mountains (about 61 m); Organ-southern San Andres Mountains (69 m thick at Bear Canyon); Pinos Altos Range/Silver City Range (32 m thick); Alamo-Hueco and Dog Mountains. Absent in the Franklin Mountains.
Type locality: none. Described from Lake Valley mining district, Sierra County.
Correlation: In the Silver City area, Laudon and Bowsher (1949) divided into, from base to top, Andrecito, Alamogordo, Nunn, and Tierra Blanca members. In the San Andres Mountains, Laudon and Bowsher and Kottlowski (1960, 1963, 1965) describe two additional members, the Doña Ana and Arcente Members.
Lithology: Mainly limestone with marl, sandy limestone, and chert. Minor crinoidal limestone and localized occurrences of metamorphic assemblages within the aureole of the Organ batholith. Complicated by intertonguing, facies changes, and highly variable thicknesses of units, requiring fossil evidence for certain identification (Seager, 1981).
Fossils: crinoids
Depositional environment: May record initial subsidence in the Orogrande Basin. Shelf marine deposit; karst north of Bishop Cap.
Stratigraphic relations to underlying rocks or predecessor(s): Disconformable on Percha (Florida Mountains); Caballero Formation
Stratigraphic relations to overlying rocks or successor(s): Interfingers with Rancheria Formation; disconformably overlain by Hueco Limestone (Florida Moutains)

Commodities: May be an important source of high-calcium limestone; extent unknown (Kottlowski, 1962). See Chloride Flat district. Copper deposits at Continental mine. Sphalerite ore at Pewabic mine (Hanover-Fierro stock) adjacent to granodiorite dikes. Manganese deposits in Lone Mountain district. Skarn deposits (copper) in Piños Altos district.

Las Cruces Formation (Laudon and Bowsher, 1949; Harbour, 1972; Setra, 1976; Seager, 1981)
Age: Late Mississippian, Meramecian
Occurrence/thickness: Organ Mountains, exposed at Stephenson-Bennett mine; San Andres Mountains, very thin to absent; Franklin Mountains, 15-27 m thick, Vinton Canyon; thins northward from Bishop Cap. At Bishop Cap, highly variable thickness (0-15 m); fills erosional depressions in the underlying Lake Valley Limestone.
Type locality: Southwest side of small south fork of shallow canyon that leaves the west slope of Franklin Mountains, directly east of Vinton, about 3.4 km south of the New Mexico-Texas state line. SW1/4, sec. 67, Blk 82, El Paso Co. TX (Laudon and Bowsher, 1949)
Correlation:
Lithology: Distinctive, thin- to medium-bedded black micrite with scattered chert; may contain metamorphic minerals locally. In the Franklin Mountains, it is indurated, aphanitic limestone, rarely fossiliferous, (although bioturbated) and chert-free. Metamorphic minerals such as garnet, specularite, diopside, wollasotnite, epidote, hematite, tremolite, and idocrase, locally.
Fossils: A few ostracod specimens and conodont suites were used to learn the age of the Las Cruces Formation.
Depositional environment: Deep-water marine
Stratigraphic relations to underlying rocks or predecessor(s): In the Franklin Mountains (Vinton Canyon), overlies Devonian rocks and is limited to the northern part of the range. In the Organ Mountains, unconformably overlies the Lake Valley Limestone.
Stratigraphic relations to overlying rocks or successor(s):
Commodities:

Last Chance Andesite (Strongin, 1958; Strangway and others, 1976; Ratté, 1981; Marvin and others, 1987)
Age: Tertiary; Oligocene and Miocene
Occurrence/thickness: Sierra Rica/Apache Hills; Fremont mining district; Apache No. 2 district
Type locality: not evaluated by USGS Geologic Names Committee
Correlation:
Lithology: andesite
Fossils:
Depositional environment:
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities: contains quarttz veins containing Pb, Ag, Cu, in Apache No 2 district

Lead Camp Limestone Magdalena Group (Bachman and Myers, 1969; Seager, 1981)
Age: Pennsylvanian (Lower and Middle according to Seager, 1981)
Occurrence/thickness: Bishop Cap, southern Organ Mountains (236 m thick); Franklin Mountains (458 m thick); southern San Andres Mountains (98 m thick).
Type locality: NW 1/4 sec 19, T. 18 S., R. 4 E., Dona Ana Co, named for canyon in southern San Andres Mountains (Bachman and Myers, 1969)

Correlation:
Lithology: Cherty limestone and dolomite, interbedded shale. In the Organ Mountains, uppermost beds are dolomitic, shaly, gypsiferous. In southeastern San Andres Mountains, Lead Camp is a distinctive sequence of limestone interbedded with porcellanite, black shale, sandstone, crossbedded quartzite, and conglomerate.
Fossils:
Depositional environment: Near-shore marine
Stratigraphic relations to underlying rocks or predecessor(s): Disconformably overlies Rancheria.
Stratigraphic relations to overlying rocks or successor(s): Grades into Panther Seep Formation, Organ Mountains and southern San Andres Mountains.
Commodities: San Andrecito-Hembrillo District: Sedimentary hydrothermal deposits; gypsiferous in the Organ Mountains. Thermally metamorphosed to quartzite adjacent to the Organ batholith; impure limestone and dolomite may contain small quantities of metamorphic garnet, specularite, diopside, wollastonite, epidote, hematite, tremolite, and idocrase. Barite deposits in San Andrecito-Hembrillo district

Little Florida Mountains, andesite of (ref)
Age:
Occurrence/thickness: East Potrillo Mountains, Little Florida Mountains
Type locality:
Correlation:
Lithology: andesite
Fossils:
Depositional environment:
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities:

Little Florida Mountains, fanglomerate of (Clemons, 1982)
(ref)
Age: probably middle Miocene
Occurrence/thickness: East Potrillo; at least 610 m thick (Clemons, 1982); Little Florida Mountains
Type locality:
Correlation:
Lithology: breccia, conglomeratic sandstone
Fossils:
Depositional environment: Probable northeast transport of clasts. Probably represents early stage of Basin-and-Range faulting.
Stratigraphic relations to underlying rocks or predecessor(s): Angular unconformity with volcanic rocks
Stratigraphic relations to overlying rocks or successor(s):
Commodities: Manganese, barite, fluorite

Little Hat Top Conglomerate (Zeller, 1975; Drewes, 1991)
Age: Tertiary, Oligocene
Occurrence/thickness: Alamo-Hueco and Dog; Big Hatchet Mountains
Type locality: none. probably named for butte located just south of Big Hatchet Peak quadrangle, Hidalgo Peak quadrangle, Hidalgo Co (Zeller, 1975)

Correlation:
Lithology:
Fossils:
Depositional environment:
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities:

Llanoria Quartzite (Harbour, 1960)
Age: Precambrian
Occurrence/thickness: Franklin Mountains
Type locality:
Correlation:
Lithology:
Fossils:
Depositional environment:
Stratigraphic relations to underlying rocks or predecessor(s): younger than Mundy Breccia and Castner Limestone
Stratigraphic relations to overlying rocks or successor(s): older than Thunderbird Group; intruded by Red Bluff Granite (1.1 b.y. old) and diabase dikes. Unconformably overlain by Bliss.
Commodities:

Lobo Formation (Darton, 1916; Clemons, 1984; Lawton and Clemons, 1992)
Age: Tertiary? In Florida Mountains, may be late Paleocene or early to middle Eocene (Seager and Clemons, 1975), although the unit was mapped by Clemons (1984) and assigned a Tertiary and Cretaceous age.
Occurrence/thickness: East Potrillo; Florida Mountains (as much as 150 m); Black Mountains/Knight Peak area (as much as 24 m thick). Strata assigned to Lobo are present at Fluorite Ridge and similar rocks occur in the Victorio Mountains (but these are not correlative)(Lemley, 1982). Rocks of similar redbed composition in the region have been variously described as Lobo Formation, Abo Formation, or Bisbee(?) Group (Darton, 1916; Jicha, 1954; Clemons, 1984; Kottlowski, 1954, 1960, 1963; Corbitt, 1971; Thorman and Drewes, 1980)
Type locality: None. Named for Lobo Draw, east slope of Florida Mountains, Luna Co. (Darton, 1916)
Correlation: Starvation Draw Member of the Rubio Peak Formation, as mapped by Clemons (1982) in the Cookes Range. In early reports, this unit has been confused with earlier red bed units, such as the Abo and Hueco Formations, which are Permian (Wolfcampian) in age, and with the Bisbee(?) Group of Cretaceous age. Both the the Lobo Formation and the Starvation Draw Member, Rubio Peak Formation, were mapped in the Florida Mountains by Clemons and Brown (1983).
Lithology: Shale, nodular shaly limestone, siltstone, sandstone, arenite, arkose, and pebble to cobble conglomerate. Divided into four petrofacies in the Florida Mountains and Fluorite Ridge, based on framework composition (James and Russo, 1988).
Fossils:
Depositional environment: Terrestrial deposits (alluvial fan and pediment); volcanic tuffs, warm springs deposits, playa deposits. All were deposited on the flanks of the Laramide Burro Mountains uplift (Seager, 1983; Seager and Mack, 1986; Seager and others, 1986; Mack and Clemons, 1988). May be a karst-filling deposit in the Florida Mountains.

Stratigraphic relations to underlying rocks or predecessor(s): Unconformable with Precambrian rocks, Montoya Group, and Hueco Group, Florida Mountains; unconformable on Precambrian granite, Black Mountains/Knight Peak area (probably Abo Formation).
Stratigraphic relations to overlying rocks or successor(s): Unconformable with Tertiary rhyolite, Black Mountains/Knight Peak area (probably Abo Formation). Overlain by Rubio Peak Formation (Clemons, 1984)
Commodities:

Love Ranch Formation (Kottlowski and others, 1956; Seager, 1981, 1989; Seager and others, 1976)
Age: Tertiary 32 m.y. (K-Ar whole-rock, Marvin and others, 1988) ; probably of Paleocene and Eocene age; late Laramide deposit. Age of the Love Ranch is determined by stratigraphic succession (i.e., intertonguing with the underlying McRae and overlying Palm Park Formations) rather than by direct radiometric dating or fossil evidence.
Occurrence/thickness: South-central New Mexico; the formation thins over uplifts and thickens into adjacent basins. Organ and southern San Andres Mountains (at least 610 m thick; the Love Ranch basin); San Diego Mountain, exposed only in Tonuco Uplift area (Seager, 1975); Doña Ana Mountains; Rincon Hills; Cedar Hills/Selden Hills (200 ft thick); Mount Riley and Mt. Cox, East Potrillo Mountains
Type locality: None. Section measured at center of SW 1/4, sec. 19, T. 20 S., R. 4 E., Dona Ana Co. (Kottlowski and others, 1956)
Correlation: May be equivalent to the Lobo Formation to the west.
Lithology: Clastic rocks (conglomerate, sandstone, siltstone), uncommon lenses of andesite and tuff breccia.
Fossils: In the San Diego Mountain area, a 1.5-m-thick ostracod-bearing limestone. Poorly preserved plants in San Andres Mountains.
Depositional environment: Terrestrial deposits (alluvial fan and pediment); volcanic tuffs, warm springs deposits, playa deposits. All were deposited on the flanks of the Laramide Rio Grande uplift (Seager, 1983; Seager and Mack, 1986; Seager and others, 1986; Mack and Clemons, 1988). Poorly sorted, coarse grained. Results from Laramide uplift that caused erosion of Paleozoic and Mesozoic rocks, depositing large amounts of debris into deep basins, such as the Jornada del Muerto Basin, adjacent to the uplifts. Many internal unconformities, faults, and folds that record individual fault-block uplift events.
Stratigraphic relations to underlying rocks or predecessor(s): Unconformable on strata as young lower Eocene and as old as Precambrian; intertongues with McRae Formation. Overlies Hueco-Abo rocks near Stephenson-Bennett and Modoc mines areas, Organ Mountains.
Stratigraphic relations to overlying rocks or successor(s): Intertongues with and grades upward into the Palm Park Formation. Pronounced angular unconformity with McRae(?) Formation near Love Ranch, southern San Andres Mountains; unconformably on steeply dipping Pennsylvanian and Permian carbonates in Organ Mountains; unconformably overlies Hueco Formation in Robledo Mountains. Disconformable with Palm Park Formation in the Tonuco uplift area.
Commodities:

Macho Andesite (Jicha, 1954)
Age: Tertiary, early?
Occurrence/thickness: Cookes Range (305 m thick)
Type locality: None. Named from Macho mining district, Sierra Co (Jicha, 1954)
Correlation:

Lithology: pyroxene andesite
Fossils: n.a.
Depositional environment:
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities: In Old Hadley District, Cookes Range, volcanic-epithermal veins

Magdalena Group (Gordon, 1907; Nelson, 1940; Lasky, 1947; Kelley and Silver, 1952; Jicha, 1954; Bachman and Hayes, 1958; Pray, 1959; Harbour, 1972; Maxwell and Oakman, 1990)
Age: Early, Middle, and Late Pennsylvanian
Occurrence/thickness: Bishop Cap (on surface and in subsurface); Black Range (214 m thick); Cobre Uplift (153-244 m thick); Cookes Range, Fluorite Ridge (probably Magdalena Group; designated as undifferentiated Pennsylvanian strata about 56 m thick); Franklin Mountains (462 m thick, excluding the Panther Seep Formation); Little Hatchet Mountains (427 m thick). Subdivided into (oldest to youngest) La Tuna, Berino, Bishop Cap, and Panther Seep Formations in the northern Franklin Mountains, La Tuna and Berino Formations at Bishop Cap, and into the Oswaldo and Syrena Formations in the Pinos Altos Range/Silver City Range(Oswaldo and Syrena Formations).
Type locality: None. Named for Magdalena Mountains, Socorro Co. (Gordon, 1907)*f*
Correlation/subdivision: May be approximately correlative to the Lead Camp Limestone that occurs to the north in the San Andres and Organ Mountains.
Lithology: Limestone, fine-grained chert, shale, and shaly and cherty limestone. South and east of the Cookes Range and in the Black Range, includes limestone and chert pebble conglomerate with limestone matrix.
Fossils: Fossiliferous; including fusulinids
Depositional environment:
Stratigraphic relations to underlying rocks or predecessor(s): In the northern Franklin Mountains, conformably overlies Helms.
Stratigraphic relations to overlying rocks or successor(s): In the northern Franklin Mountains, grades into overlying Hueco Limestone.
Commodities: Copper deposits at Continental mine. Lost Treasure and Gold Quartz mines replacement manganese; iron manganese skarns at Hamlett claims. Replacement and skarn deposits (copper) in Piños Altos district. Gypsum deposits locally. Supergene iron deposit in sheared zones, Copiapo Mine, Franklin Mountains.

Mancos Shale Dane, Wanek and Reeside, 1957; Fassett and Jentgen, 1978; Seager, 1981; Cobban, 1988)
Age: Early and Late Cretaceous, Cenomanian, Turonian, Coniacian, Santonian, Campanian (local)
Occurrence/thickness: Widespread in Colorado, Arizona, Wyoming, Utah, Colorado and New Mexico. The shale and sandstone units have been subdivided into upper and lower shale units by an intervening sandstone tongue. Steeple Rock (Virden) area (70-96 m thick); Santa Rita area (100 m thick), San Andres Mountains (214 m near Love Ranch correlated with the Eagle Ford Shale). West of Hembrillo Pass, 139 m of Mancos in subsurface, with arenaceous beds in lower part. Nearshore arenaceous facies rocks, as much as 92 m thick, are prominent in the Mancos Shale between Hembrillo and Ash Canyons, and has been correlated with the Tres Hermanos Sandstone Member of the Mancos (Hook, *in* Seager, 1981).

Type locality: None. Named for occurrence in Mancos Valley and about town of Mancos, between La Plata Mountains and Mesa Verde, Montezuma Co. CO (Cross, 1899)
Correlation: In the southern San Andres Mountains near Love Ranch, the sandstone tongue is correlated, using fossil evidence, with the Tres Hermanos Sandstone Member of the Mancos. Shale and sandstone unit above the sandstone tongue is probably correlative with the Gallup Sandstone (S.C. Hook, pers. communication, *in* Seager, 1981, p. 34). Kottlowski and LeMone (1994) state that the Mancos, a black shale unit above the Dakota, does not occur in the northern part of the San Andres Mountains, but that an intercalated calcareous sandstone, subgraywacke, and carbonaceous shale with bone coal overlies Dakota beds that contain abundant fossils; they suggest correlation of this sandstone unit with the Eagle Ford Shale that occurs near El Paso. Molenaar suggests correlation with the lower part of the Colorado Formation in southwestern New Mexico.
Lithology: Calcareous siltstone, limestone and calcarenite
Fossils: Fossil shark teeth, inoceramids, ammonites [Steeple Rock (Virden) area]
Depositional environment: nearshore marine
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s): Unconformable with Tertiary Love Ranch, San Andres Mountains
Commodities:

Maverick Hill dacitic lava
Age:
Occurrence/thickness: Steeple Rock, Hells Hole area
Type locality:
Correlation:
Lithology: dacite
Fossils:
Depositional environment: lava flow
Stratigraphic relations to underlying rocks or predecessor(s): andesitic lava of Pine Cienega Peak
Stratigraphic relations to overlying rocks or successor(s):
Commodities:

McGhee Peak Formation (Bisbee Group)(Gillerman, 1958; Hayes, 1970; Armstrong and others, 1978; Drewes, 1986)
Age: Early Cretaceous
Occurrence/thickness: Central Peloncillo Mountains
Type locality: Named for McGhee Peak, sec. 34, T. 24 S. R. 21 E., Hidalgo County
Correlation:
Lithology:
Fossils:
Depositional environment:
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities:

McRae Formation (Kelley and Silver, 1952; Bushnell, 1953, 1955; Segerstrom and others, 1979; Lozinsky, 1986; Buck and Mack, 1992)
Age: Late Cretaceous, early Tertiary

Occurrence/thickness: Cookes Range; questioned in the southern San Andres Mountains. McRae thickens within south-central New Mexico to 300 m in the vicinity of Elephant Butte just north of the study area.
Type locality: Base of Elephant Butte and along most of the eastern shoreline of Elephant Butte Reservoir for several mi north of the dam, Sierra Co., NM. Named from old Fort McRae, located in an eastern tributary of the Rio Grande about 4.8 km north of Elephant Butte (Kelley and Silver, 1952).
Correlation:
Lithology: lower Jose Creek Member, upper Hall Lake Member (Buck and Mack, 1992)
Fossils: Paleoflora that indicate arid environment (Buck and Mack, 1992); dinosaur remains
Depositional environment: Fluvial, alluvial, ash-fall tuff. Paleosols present. Probably represents early Laramide orogenic deposition.
Stratigraphic relations to underlying rocks or predecessor(s): Possibly overlies the Love Ranch Formation in the southern San Andres Mountains.
Stratigraphic relations to overlying rocks or successor(s): Intertongues with the Love Ranch Formation in the Jornada del Muerto basin (Seager, 1981).
Commodities:

Mesilla Valley Shale (Lovejoy, 1976; Strain, 1976; Norland, 1985)
Age: Early Cretaceous, Comanchean, late Albian
Occurrence/thickness: Cerro de Cristo Rey (55 m thick)
Type locality: NW 1/4, NW 1/4 NE 1/4 sec 16, T. 29 S., R. 4 E., Dona Ana Co. Named for an agricultural area on Rio Grande floodplain north of Cerro de Cristo Rey and in Dona Ana Co (Strain, 1976)
Correlation:
Lithology: shale, ironstone, sandstone, limestone
Fossils: *Trigonia*; "*Haplostiche*"
Depositional environment:
Stratigraphic relations to underlying rocks or predecessor(s): Muleros Formation
Stratigraphic relations to overlying rocks or successor(s): Anapra Formation
Commodities: Extensively quarried for brick clay. May be oil–prone (Norland, 1985).

Mimbres Conglomerate of Hernon and others (1953) (Hernon and others, 1953; Jicha, 1954 ; Clemons, 1980, 1982, 1984)
Age: Tertiary, Oligocene (about 32 m.y.), Pliocene, Quaternary, Pleistocene. Age modified to Pliocene to Pleistocene (Clemons, 1982)
Occurrence/thickness: Black Range; Cookes Range; Mimbres Mountains; pediment surfaces surrounding the Florida and Little Florida Mountains (up to 92 m thick), Mimbres Valley
Type locality: an informal unit that has been designated as Gila Formation (Corbitt, 1971) and Mimbres Formation (Clemons, 1984)
Correlation: Camp Rice Formation; pitchstone, sandstone, and tuff unit of Jones and others, 1967; rhyolite of Moccasin John area of Ericksen and others, 1970; Faywood rhyolite.
Lithology: Caliche (up to several ft thick), gravel, sand. Tuffs, epiclastic strata, flow-banded rhyolite domes, flows. Tuffs and epiclastic strata are up to 244 m thick.
Fossils:
Depositional environment: Fan deposits, piedmont valley fill and slope deposits, erosion-surface veneers, closed basin deposits. Tuffs and epiclastic strata represent moat deposits of the Emory caldera; flow-banded rhyolite domes and flows are related to moat and ring fracture deposits of the Emory caldera (Elston and others, 1975).

Stratigraphic relations to underlying rocks or predecessor(s): Kneeling Nun Tuff
Stratigraphic relations to overlying rocks or successor(s): Box Canyon Rhyolite
Commodities: Caliche, gravel .

Mimbres Peak Formation (Elston, 1957; Strangway and others, 1976)
Age: Tertiary, Oligocene
Occurrence/thickness: Cookes Range (61 m thick); Black Range/Mimbres Mountains
Type locality: none
Correlation:
Lithology: flow–banded rhyolite
Fossils: n.a.
Depositional environment: volcanic
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities: Perlite at Schwartz deposit near Santa Rita

Mojado Formation (Zeller, 1962, 1965, 1970, 1975, 1976; Zeller and Alper, 1965; Hayes, 1970; Soule, 1972; Drewes, 1991)
Age: Early to Late Cretaceous; Albian to early Cenomanian
Occurrence/thickness: Alamo-Hueco and Dog; Animas Mountains; Big Hatchet Mountains (1,585 m thick); Brockman Hills; Cookes Range; Little Hatchet Mountains (about 1,525 m); Peloncillo Mountains; Pyramid Mountains; Sierra Rica; Alamo-Hueco-Dog Mountains, East Potrillo Mountains.
Type locality: Section: sec 20, T. 32 S., R. 15 W., Hidalgo Co. named for Mojado Pass, Big Hatchet Mountains (Zeller, 1965)
Correlation:
Lithology: Sandstone, shale, minor impure limestone, limestone and sandstone conglomerate. Northern Animas Mountains; bioclastic and biohermal to finely micritic limestone, interbedded shale and siltstone; Alamo-Hueco-Dog Mountains, orthoquartzite interbedded with shale. Subdivided into lower, middle, and upper units in the Little Hatchet and Big Hatchet Mountains.
Fossils: Rudisitd brachiopods, Orbitolina foramininfera, pelecypods, other mollusks in bioherms; petrified wood
Depositional environment: Partly marine, deltaic. Lower member, shallow marine; middle member, fluvial; upper member, marine.
Stratigraphic relations to underlying rocks or predecessor(s): Conformable with U-Bar Formation. Animas Mountains: Mojado gradational into the U-Bar Formation near Winkler Anticline.
Stratigraphic relations to overlying rocks or successor(s): Locally overlain by Cowboy Spring Formation; may be unconformable with Tertiary rocks. In Little Hatchet Mountains, unconformably overlain by Ringbone Formation; north of Granite Pass, the upper part of the formation is cut by a granite stock (Zeller, 1970; Mack and others, 1986).
Commodities:

Montoya Group (Richardson, 1908; Darton, 1916; Paige, 1916, Kelley, 1951; Kelley and Silver, 1952; Pray, 1953, 1958; Zeller, 1965; Thorman and Drewes, 1981; Drewes, 1991; Poole and others, 1992)
Age: Middle and Late Ordovician, Champlainian and Cincinnatian
Occurrence/thickness: Apache Hills, Animas Mountains (98 m thick), Big Hatchet Mountains (117 m thick), Black Range-Lake Valley area (63-122 m thick), Cedar Mountains (61 m,

top not exposed), Cookes Range (98 m thick), Bishop Cap, East Potrillo Mountains, Florida Mountains (up to 100 m thick), northern Franklin Mountains (as much as 122 m thick), Klondike Hills (Cable Canyon Sandstone), Mimbres Valley, Lone Mountain, Organ-San Andres Mountains, Peloncillo Mountains, Pinos Altos Range/Silver City Range (92-107 m thick), Robledo Mountains (64 m-76 m thick), Sierra Rica, Victorio Mountains (101 m thick). In the Peloncillo Mountains where Ordovician rocks were probably eroded prior to Devonian sedimentation, Drewes and Thorman (1980) mapped the Montoya with the El Paso Limestone; this undivided unit is estimated to be 180-200 m thick. The unit is missing in extreme southwestern New Mexico (Clemons and Mack, 1988). Eastern outcrops subdivided into (base to top) Cable Canyon Sandstone, Upham Dolomite, Aleman Dolomite (Formation), and Cutter Dolomite (Formation). In some parts, the Montoya has Formation status, owing to insufficient thickness.

Type locality: None. Origin of name not given. Occurs in El Paso and Van Horn quadrangles, El Paso and Culberson Cos. TX (Richardson, 1908)

Correlation/ subdivisions: Divided into Jornada Limestone and Cable Canyon Sandstone (Kelley, 1951) then redivided into Cable Canyon Sandstone (base), Upham Dolomite, Aleman Formation, and Cutter Formation (top) (Kelley and Silver, 1952)

Lithology: Sandstone, dolomite, dolomitic siltstone, and limestone. Commonly resistant to erosion. Minor lenticular banded chert.

Fossils: Brachiopods, trilobites, gastropods, sponges, coelenterates, nautiloids, corals, bryozoans, and possibly some conodonts. Recrystallized in some ranges.

Depositional environment: Shallow marine. Warm, well-aeriated, shallow subtidal environment (Hayes, 1975)

Stratigraphic relations to underlying rocks or predecessor(s): Disconformable or unconformable on El Paso.

Stratigraphic relations to overlying rocks or successor(s): Northward from the Robledo Mountains, the Montoya is erosionally thinned. Unconformable with Fusselman in southern Organ Mountains.

Commodities: Marble, limestone (locally thermally metamorphosed to marble adjacent to Organ batholith). San Andrecito-Hembrillo District: Vein- and replacement-deposits. Manganiferous iron ore in the Chloride district (Boston Hill and Chloride Flat mines, is an intimate mixture of hematite and pyrolusite. Manganese deposits, Rincon district.

Morita Formation, Bisbee Group (Ransome, 1904; Hayes, 1970, 1982; Drewes and Thorman, 1980; Drewes, 1986)

Age: Early Cretaceous

Occurrence/thickness: Cookes Range; Peloncillo Mountains (186 m thick, faulted); Little Hatchet Mountains.

Type locality: none. Named for Morita Hills of Mexico, which lie just to the south of Bisbee 15' quadrangle, Cochise Co., southeastern AZ.

Correlation:

Lithology: Shale and siltstone, minor interbedded sandstone and limestone-clast pebble conglomerate

Fossils: Oysters, pelecypods, gastropods, colonial corals, echinoids, foraminifera, fossil wood.

Depositional environment: Marine, biohermal reef deposits

Stratigraphic relations to underlying rocks or predecessor(s): Conformable with Hell-to-Finish Formation in the Animas Mountains, near Winkler Anticline, and in Mojado Pass between the Alamo-Hueco and Big Hatchet Mountains.

Stratigraphic relations to overlying rocks or successor(s):

Commodities:

Muleros Formation (Lovejoy, 1976; Strain, 1976)
Age: Early Cretaceous, Comanchean and late Albian
Occurrence/thickness: Cerro de Cristo Rey (at least 38 m thick)
Type locality: section: SE1/4 SE1/4 NE1/4 sec 16, T. 29 S., R. 4 E., Dona Ana Co. Named for Cerro de Muleros, which is original name for Cerro de Cristo Rey (Strain, 1976)
Correlation:
Lithology: limestone (packstone), siltstone, shale
Fossils: *Gryphaea* (Ostrea) abundant
Depositional environment:
Stratigraphic relations to underlying rocks or predecessor(s): Smeltertown Formation
Stratigraphic relations to overlying rocks or successor(s): Mesilla Valley Formation
Commodities:

Mullen Peak dacitic lava
Age:
Occurrence/thickness: Steeple Rock, Hells Hole area
Type locality:
Correlation:
Lithology: dacite
Fossils:
Depositional environment: lava flow
Stratigraphic relations to underlying rocks or predecessor(s): andesitic lava of Pine Cienega Peak
Stratigraphic relations to overlying rocks or successor(s):
Commodities:

Mundy Breccia (Harbour, 1960, 1972)
Age: Precambrian, Proterozoic
Occurrence/thickness: Cookes Range; Franklin Mountains
Type locality: 2.4 m southeast of North Franklin Mountain and 0.8 km northwest of mouth of Fusselman Canyon, El Paso Co. TX. Named for spring on eastern slope of Franklin Mountain (Harbour, 1960)
Correlation:
Lithology:
Fossils:
Depositional environment:
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities:

Mural Limestone (Bisbee Group) (Ransome, 1904; Imlay, 1939; Gilluly, 1956; Sabins, 1957; Hayes and Raup, 1968; Drewes and Thorman, 1980; Drewes, 1981, 1986, 1987; Hayes, 1970, 1982; Drewes, du Bray, and Pallister, 1995)
Age: Early Cretaceous, Albian
Occurrence/thickness: Animas Mountains; Sierra Rica and Apache Hills; Cookes Range
Type locality: None. Named for Mural Hill, east of Bisbee in Cochise Co., AZ (Ransome, 1904)
Correlation:
Lithology:

Fossils:
Depositional environment:
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities:

Naco Group (Horquilla, Earp, Colina, Scherrer, Concha) (Ransome, 1904; Darton, 1925; Hernon, 1935; Stoyanow, 1936; Gilluly, Cooper, and Williams, 1954; Sabins, 1957; Gillerman, 1958; Zeller, 1965; Hayes and Landis, 1965; Drewes, 1971, 1975; Armstrong and others, 1978; Drewes and Thorman, 1980; Clemons and Mack, 1988)
Age: Pennsylvanian and Permian
Occurrence/thickness: Cookes Range; Big Hatchet Mountains; Peloncillo Mountains [Pennsylvanian ranges from 763 m in Big Hatchet Mountains to nil between the Tres Hermanas and Florida Mountains (Clemons and Mack, 1988)]
Type locality: Named for Naco Hills, Bisbee 15' quadrangle, Cochise Co., AZ (Ransome, 1904)
Correlation:
Lithology:
Fossils:
Depositional environment:
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities:

Oak Creek Tuff (Zeller and Alper, 1965)
Age: Tertiary
Occurrence/thickness: Cookes Range; Animas Mountains (488 m thick); Alamo-Hueco-Dog Mountains (up to 229 m thick);
Type locality: None. Named for exposures near Oak Creek, Animas Mountains SE 1/4 T. 30 S., R. 18 W., Walnut Wells quadrangle, Hidalgo Co. (Zeller and Alper, 1965)
Correlation:
Lithology:
Fossils:
Depositional environment: Fill of Juniper caldera
Stratigraphic relations to underlying rocks or predecessor(s): Conformable on tuff of Wood Canyon
Stratigraphic relations to overlying rocks or successor(s):
Commodities: radioactive veins of opal and quartz at Opportunity claims, Antelope Wells-Dog Mountains district.

Oñate Formation (Stevenson, 1945; Cooper and Dutro, 1982; Kottlowski, 1963; Flower, 1959)
Age: Middle Devonian, late Givetian
Occurrence/thickness: The Oñate is as thick as 30 m in the northern Franklin Mountains; San Andres Mountains (4.5-9.8 m thick); Cookes Range; in the northern Selden Hills/San Diego Mountain/Tonuco Uplift area (at least 46 m thick); may constitute a slide block (Seager, 1975). Isopachs of the Oñate in southwestern N. Mex., the Jarilla Uplift(?), and the Burro Uplift, are given in Kottlowski (1963, fig. 7).
Type locality: North slope San Andres Canyon near abandoned mine in sec 18, T. 18 S., R. 4 E., Dona Ana Co. (Stevenson, 1945)
Correlation:

Lithology: Thin-bedded dolomitic very fine sandstone, siltstone, and shale.
Fossils: well-preserved brachiopods, bryozoans
Depositional environment:
Stratigraphic relations to underlying rocks or predecessor(s):Overlies Montoya Dolomite in San Andres Mountains
Stratigraphic relations to overlying rocks or successor(s): Transitional into the Sly Gap Formation
Commodities:

Orejon Andesite (Dunham, 1935)
Age: Tertiary, late Eocene to early Oligocene
Occurrence/thickness: Cookes Range, Organ-San Andres Mountains
Type locality: none. Named for mine in Organ Mountains, Dona Ana Co. (Dunham, 1935)
Correlation: Synonymous with Palm Park Formation (Elston, 1976)
Lithology: Mostly of andesitic, rhyolitic, to dacitic composition. Early stage of andesitic to dacitic volcanism; later stage of rhyolitic composition. Later stage is thought to be co-magmatic with the Organ batholith.
Fossils:
Depositional environment: Tuffs, flows, breccias, volcaniclastic sediments. Roof pendants within the roof of the batholith and the rocks that make up the batholith are mostly Eocene in age. Forms the roof of, as well as roof pendants within, the Organ batholith that intrudes it. Vents have not been found and are thought to have been eroded by subsequent uplift or buried by surficial deposits. Faulted against Hueco on the west flank of the San Andres Mountains north of Organ.
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s): Volcanic rocks that comprise the caldera edifice are named the Orejon Andesite; volcanic units that overlie it are termed the Organ caldera complex.
Commodities:

Organ Needle quartz syenite (Seager, 1981; Seager and McCurry, 1988)
Age: Tertiary
Occurrence/thickness: Organ Mountains (Organ batholith)
Type locality: none.
Correlation:
Lithology: quartz monzonite
Fossils:
Depositional environment: Intrusive unit of the Organ batholith complex
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities:

Oswaldo Formation (Magdalena Group) (Harbour, 1972; Cunningham, 1974; Jones and others, 1970)
Age: Middle to Upper Pennsylvanian
Occurrence/thickness: Cookes Range; Pinos Altos Range/Silver City Range (53-128 m thick); commonly faulted and folded. (Jones and others, 1970)
Type locality:
Correlation:

Lithology: Limestone, thin shale, sandstone lenses, siliceous shale at base. Abundant chert nodules.
Fossils: Crinoidal
Depositional environment:
Stratigraphic relations to underlying rocks or predecessor(s): Disconformable on the Lake Valley limestone
Stratigraphic relations to overlying rocks or successor(s): Conformable with Syrena Formation
Commodities: magnetite and sphalerite (Copper Flat district); replacement manganese, Bear Mountain group of claims, Fleming district. Manganese deposits in Lone Mountain district. Skarn deposits (copper) in Piños Altos district and Santa Rita district. Disseminated iron in non-magnesian limestone, Santa Rita district, where in contact with intrusives.

Outlaw Mountain dacite
Age:
Occurrence/thickness: Cookes Range; Peloncillo Mountains (Geronimo Trail caldera)
Type locality:
Correlation:
Lithology: dacite
Fossils:
Depositional environment:
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities:

Packer's Trail, rhyolite of (ref)
Age:
Occurrence/thickness: San Luis Mountains [San Luis caldera dated at 23-24 m.y. (Deal and others, 1978)]; Cookes Range
Type locality:
Correlation:
Lithology:
Fossils:
Depositional environment:
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities:

Palm Park Formation (Kelley and Silver, 1952; Kottlowski and others, 1969; Seager and Clemons, 1975, 1976, 1979; Marvin and Cole, 1978; Loring and Loring, 1980)
Age: Tertiary, mostly of late Eocene age; 35.9-51.5 Ma (Kelley and Silver, 1952; Clemons, 1979)
Occurrence/thickness: Widespread in Doña Ana County; it is present in the Sierra de las Uvas and Goodsight Mountains (up to 1,067 m thick), Robledo Mountains, Rincon Hills, Doña Ana Mountains (at least 595 m thick; incomplete sections), San Diego Mountain (generally about 610 m thick, but thins over hills produced by Laramide deformation), Tonuco uplift area, and the East Selden Hills and Cedar Hills (31-915 m thick). Also in Cookes Range and Cedar Hills. Highly variable in thickness. Forms the floor of the eastern Good Sight-Cedar Hills depression.

Type locality: Valley known as Palm Park, located along the southeastern edge of Caballo area, Sierra Co. However, no complete section was measured, and the lower part of the formation was dropped below surface along the Palm fault. Named for Palm Park (Kelley and Silver, 1952)

Correlation: In the Organ Mountains, the Palm Park and the Orejon andesite together interfinger westward with the Rubio Peak Formation. Indistinguishable from the Rubio Peak Formation in the Good Sight Mountains. In the Doña Ana Mountains, mineralogically indistinguishable from the Cleofas Andesite.

Lithology: Andesite to latite flows, tuff breccias, lahars, and hypabyssal intrusives; minor dacite and basalt flows. In the Doña Ana Mountains, the Palm Park is mostly andesitic, epiclastic rock having various sedimentary and volcanic origins. In the Good Sight Mountains, the unit is mudstone, sandstone, breccia, and conglomerate, made up mostly of andesite-latite detritus.

Fossils:

Depositional environment: Epiclastic strata with a variety of volcanic affinities. Suggestive of hot spring, stream, floodplain, lahar and mudflow deposition on piedmont slopes draining volcanic highlands. Largely derived from vents in Doña Ana Mountains (Seager and others, 1976). Forms the floor of the Good Sight-Cedar Hills depression. East and West Selden Hills and Senden Canyon area is formed largely of Palm Park (block faulted remnants of rim of Good Sight-Cedar Hills depression)

Stratigraphic relations to underlying rocks or predecessor(s): Intertongues with the Love Ranch Formation in the Jornada del Muerto basin. In the Organ Mountains, the Palm Park and the Orejon andesite together interfinger westward with the Rubio Peak Formation. According to Elston, 1976, lies above McRae Formation. In Tonuco uplift, basal part of formation pinches out against Paleozoic strata (Seager, 1975).

Stratigraphic relations to overlying rocks or successor(s): According to Elston, 1976, lies below the Thurman and Bell Top Formations. In Rincon Hills, disconformable with Thurman Formation and Uvas Basaltic Andesite. In San Diego Mountains–Tonuco Uplift area, overlain by the Bell Top Formation. In Cedar Hills, overlain by Rincon Valley Formation.

Commodities: Rincon District: travertine deposits. Clays, zeolites

Panther Seep Formation Magdalena Group (Kottlowski and others, 1956; Bachman and Myers, 1969; Hair, 1976; Kelley and Matheny, 1983; Harbour, 1972; Seager, 1981)

Age: Late Pennsylvanian, Early Permian

Occurrence/thickness: Cookes Range; Franklin Mountains; Organ Mountains (610 m thick); San Andres Mountains, thickens to south. Panther Seep sediments were a major component of the Orogrande Basin; sediment sources in Pedernal Uplift to the northeast. Unit thickens to the south in the San Andres Mountains and proportion of coarse clastics decreases. The unit makes a transition into reef-like deposits of limestone and carbonaceous shale in the southern San Andres Mountains, and gypsum and argillaceous calcilutite are typical.

Type locality: SE1/4 sec 14, T. 13 S., R. 3 E., Sierra Co. (Kottlowski and others, 1956), San Andres Mountains

Correlation: In the Franklin Mountains, it is called Upper Member of the Magdalena Group by some workers.

Lithology: Silty and carbonaceous shale, argillaceous limestone, laminated calcilutite, silty calcarenite, silty calcareous sandstone, and massive biostromal limestone and biohermal reefs. San Andres Mountains (Ash Canyon), 2 thick gypsum beds; Franklin Mountains, gypsum in thin beds (2-12 m thick); Organ Mountains, shale, sandstone, siltstone, fine-

grained laminated limestone, and gypsum; Franklin Mountains, chert-pebble conglomerate at the base.

Fossils:

Depositional environment: Deltaic to brackish water (intertidal) clastic sediments with interbeds of gypsum; cyclic intertidal to supratidal and marine sediments may indicate short-term sea-level fluctuations (Schoderbek, 1991; Soreghan, 1992).

Stratigraphic relations to underlying rocks or predecessor(s): Conformable with Lead Camp Limestone, southern San Andres and the Organ Mountains.

Stratigraphic relations to overlying rocks or successor(s): Conformable with Hueco Limestone, southern San Andres and the Organ Mountains; overlain by lower Tertiary conglomerates and volcanic rocks, central and northern Organ Mountains.

Commodities: Northern Franklin Mountains District: Gypsum and limestone (high-calcium type). Small gypsum occurrences throughout the Mimbres Resource Area.

Paradise Formation (Stoyanow, 1926; Hernon, 1935; Sabins, 1957; Drewes and Thorman, 1980; Thorman and Drewes, 1981, 1991; Zeller, 1958, 1965; Armstrong and others, 1978; Gillerman, 1958; Armstrong, 1962, 1970; Bromfield and Wrucke, 1961)

Age: Late Mississippian, Meramecian and Chesterian

Occurrence/thickness: Animas Mountains (as much as 23 m thick); Big Hatchet Mountains (97 m thick); Cedar Mountains (about 70 m); Cookes Range; Klondike Hills (67 m thick); Peloncillo Mountains (12-37 m thick due to faulting; northernmost and westernmost exposures in New Mexico); Sierra Rica. Isopachs of the Paradise and Helms in southern N. Mex., the Jarilla Uplift(?), and the Burro Uplift, are given in Kottlowski (1963, fig. 8). Effected by Late Mississippian (Ouachita) uplift; eroded north of about 33° N. latitude. Karst development in the Paradise and underlying carbonates during uplift events. Typically, is highly lenticular; shows evidence of abrupt facies changes. Thinned by faulting.

Type locality: None. Named for outcrops a few km east of Paradise, Chiricahua Mountains, Cochise Co., AZ (Stoyanow, 1926)

Correlation: Equivalent to the Helms Formation, eastern part of the Mimbres Resource Area

Lithology: Crystalline limestone intercalated with shale, mudstone, oolite, calcareous sandstone and siltstone, and arenaceous limestone. Lenticular and nodular chert. Quartz sandstone beds up to 9 m thick are present in Big Hatchet Mountains.

Fossils: It is both mega- and microfauna-bearing (abundant crinoids, foraminifera and brachiopods); oolitic locally.

Depositional environment: Records a marine regression. Clearly records deposition in shallow marine to shoaling waters, with increasing input from terrestrial sources upward in the section. Records onset of the Ouachita orogeny.

Stratigraphic relations to underlying rocks or predecessor(s): Gradational into or conformable with underlying Escabrosa (Hachita Member in southwestern NM)

Stratigraphic relations to overlying rocks or successor(s): Disconformable with Horquilla in Peloncillo Mountains

Commodities:

Park Tuff (Zeller, 1962; Zeller and Alper, 1965)

Age: Tertiary, Oligocene [27.8+0.6, 29.6+0.6 (Elston and Erb, 1977; Erb, 1979), 29.62+0.62 m.y. (Deal and others, 1978)]

Occurrence/thickness: Cookes Range; Alamo-Hueco and Dog; San Luis Mountains (San Luis caldera); Animas Mountains

Type locality: None. Named from exposures around rim of The Park, Animas Mountains, secs 19–21, 29, T. 31 S., R. 18 W., Walnut Wells quad, Hidalgo Co (Zeller, 1965)
Correlation:
Lithology: Rhyolite
Fossils:
Depositional environment: Ash-flow tuff, sandstone; probably fill of the San Luis caldera (Erb, 1979); welded.
Stratigraphic relations to underlying rocks or predecessor(s): Conformable with the basaltic andesite of Bull Canyon,Alamo-Hueco Mountains; basalt of Whitewater Mountains, Animas Mountains
Stratigraphic relations to overlying rocks or successor(s):
Commodities: Pumice

Percha Shale (Gordon and Graton, 1907; Paige, 1916; Gillerman,1958; Armstrongand others, 1978; Laudon and Bowsher, 1941; Zeller, 1965; Stevenson, 1945; Kelley and Silver, 1952; Flower, 1959; Kottlowski, 1963, 1965; Cunningham, 1974; Seager, 1981; Thorman and Drewes, 1981; Drewes, 1991)
Age: Late Devonian, Famennian
Occurrence/thickness: Mainly west of the San Andres Mountains. Animas Mountains, Big Hatchet Mountains (85 m thick), Bishop Cap (43 m thick), Black Range (34-40 m thick), Cedar Mountains area (greater than 30 m, no complete section exposed) Cobre Uplift (70-96 m thick), Cookes Range (56 m thick), East Potrillo, Florida Mountains (up to 76 m thick), Franklin Mountains (average thickness range is 18-21 m), Klondike Hills (30 m thick), Lake Valley area, Organ and southern San Andres Mountains (21-26 m thick), Peloncillo Mountains (probably more than 100 m thick), Pinos Altos Range/Silver City Range (70-130 m thick), Robledo Mountains (40 m thick). Isopachs of the Percha in southwestern N. Mex., the Jarilla Uplift(?), and the Burro Uplift, are given in Kottlowski (1963, fig. 7). Subdivided in Peloncillo Mountains, Pinos Altos Range/Silver City Range, and Cookes Range areas into the lower Ready Pay Member and the upper Box Member. In the north-central Klondike Hills, the upper 100 ft of the Box Member crops out.
Type locality: section: at "The Box", 4 km southeast of Hillsboro in SW1/4, SW1/4, SE1/4, sec. 14, T. 16 S. R. 7 W., Sierra Co. (Stevenson, 1945)
Correlation/subdivisions: Type section designated; divided into Ready Pay and Box Members (Stevenson, 1945). In the Bear Canyon area (southern San Andres Mountains), the Percha contains limestone horizons that are probably correlative with the Oñate Formation described in the San Andres Mountains (Kottlowski and others, 1956; Bachman and Myers, 1969), and with the Canutillo Formation to the south in the Organ Mountains and Bishop Cap (Seager, 1981). In the Peloncillo Mountains the Ready Pay Member is probably equivalent to the Portal Formation of Sabins, 1957 (Drewes and Thorman, 1980). The Ready Pay Member has been correlated with the Sly Gap Formation of central New Mexico (Jones and others, 1967). May be correlative with the Martin, Portal, and Swisshelm Formations in southeastern Arizona.
Lithology: Generally poorly exposed; faulted parallel to bedding surfaces. Fissile, sparsely fossiliferous, basal shale that grades upwards into argillaceous, calcareous siltstone and sandstone; locally contains limestone nodules and lenses. In the Animas Mountains, the Percha is thin platy bioclastic limestone.
Fossils: Fragmentary parts of fish plates and teeth, brachiopods, bryozoa, corals, and crinoid debris. In the Cookes Range the Percha Shale includes a basal conodont-bearing siltstone.
Depositional environment:

Stratigraphic relations to underlying rocks or predecessor(s): Disconformable on the Montoya Group in the Big Hatchet Mountains. Grades downward into Canutillo beds in Franklin and southern San Andres Mountains.
Stratigraphic relations to overlying rocks or successor(s): Interbedded with Escabrosa in northern Animas Mountains
Commodities: Serves as an impermeable cap to mineralizing solutions

Pine Cienega Peak andesitic lavas (Ratté and Hedlund, 1981)
Age:
Occurrence/thickness: Steeple Rock area, Hells Hole area
Type locality:
Correlation:
Lithology:
Fossils:
Depositional environment:
Stratigraphic relations to underlying rocks or predecessor(s): rhyolite of Hells Hole
Stratigraphic relations to overlying rocks or successor(s): dacitic lavas of Maverick Hill and Mullen Peak
Commodities:

Playas Peak Formation (Bisbee Group)(Lasky, 1938; Zeller, 1970; Hayes, 1970)
Age: Early Cretaceous
Occurrence/thickness: Little Hatchet Mountains
Type locality: None designated. Named for Playas Peak in Little Hatchet Mountains (Lasky, 1938)
Correlation:
Lithology:
Fossils:
Depositional environment:
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities:

Pollack Quartz Latite (Jicha, 1954; Elston, 1957; Hedlund, 1977)
Age: Tertiary, Oligocene; not radiometrically dated
Occurrence/thickness: Southern end of the Black Range (92 m thick) and in subsurface; of limited extent (Emory caldera); Cookes Range; associated with Kneeling Nun Tuff
Type locality: Along Taylor Creek, Sierra Co. Named from exposure on Pollack Creek (Jicha, 1954)
Correlation:
Lithology: An andesite-latite porphyritic unit
Fossils:
Depositional environment: Flows and domes
Stratigraphic relations to underlying rocks or predecessor(s): Locally overlies the Mimbres Peak Formation
Stratigraphic relations to overlying rocks or successor(s): Razorback Formation
Commodities:

Potholes Country rhyolite (Ratté and others, 1982b???)

Age: Miocene
Occurrence/thickness: San Francisco district, Grant County
Type locality:
Correlation:
Lithology: rhyolite, high silica and high potassium series
Fossils:
Depositional environment: lava flows, plugs, and pyroclastic rocks
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities:

Pyramid Peak rhyolite (Deal and Elston, 1983)
Subunit name: Four members: Upper tuff member, Flow member, Lower tuff member, and Lake deposits
Age:
Occurrence/thickness: Pyramid Mountains (Muir caldera); Cookes Range
Type locality:
Correlation:
Lithology: Pumiceous tuff, sandstone, volcaniclastic conglomerate, freshwater limestone
Fossils:
Depositional environment: Tuffs, volcanic flows, playa deposits (freshwater limestone)
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities: Pumice

Rainvalley Formation (upper Naco Group) (Creasey, 1967; Wrucke and others, 1983; Drewes, 1971, 1991)
Age: Early Permian
Occurrence/thickness: Big Hatchet Mountains (provisional identification); Cookes Range
Type locality: North of Rain Valley in Mustang Mountains in NE1/4 sec 15, T. 20 S., R. 18 E., Santa Cruz Co. AZ (Bryant and McClymonds, 1961)
Correlation:
Lithology:
Fossils:
Depositional environment:
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities:

Rancheria Formation (Laudon and Bowsher, 1949; Bachman and Myers, 1969; Armstrong and others, 1980)
Age: Early and Late Mississippian, Osagean, Meramecian
Occurrence/thickness: Bishop Cap; East Potrillo; Franklin Mountains (67 m thick); Organ/San Andres Mountains; Cookes Range, Florida Mountains
Type locality: Southwest side of small fork of shallow canyon that leaves west slope of Franklin Mountains, almost directly east of Vinton, SW1/4, sec. 67, S. Blk 82, El Paso Co., TX (Laudon and Bowsher, 1949)
Correlation:
Lithology:

Fossils:
Depositional environment:
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities:

Razorback Formation (Elston, 1957)
Age: Tertiary, Oligocene
Occurrence/thickness: Black Range; Cookes Range
Type locality: None. Named for Razorback Mountain in sec. 36, T. 18 S., R. 11 W., Grant Co (Elston, 1957)
Correlation:
Lithology: basaltic andesite
Fossils:
Depositional environment: volcanic flows
Stratigraphic relations to underlying rocks or predecessor(s): overlies Emory caldera
Stratigraphic relations to overlying rocks or successor(s):
Commodities: Perlite at Schwartz deposit near Santa Rita

Red Bluff Granite (Nelson, 1940)
Age: Precambrian [1.1 billion yr old (Thomman, 1991)]
Occurrence/thickness: Franklin Mountains
Type locality: None. Occurs at Red Bluff Park (for which it is probably named) in McKelligon Canyon, Franklin Mountains, El Paso Co. TX (Nelson, 1940)
Correlation:
Lithology:
Fossils:
Depositional environment: probably formed in a rift environment
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities:

Refinery Member, Del Norte Formation (Strain, 1968; Lovejoy, 1976)
Age: Cretaceous
Occurrence/thickness: Cerro de Cristo Rey
Type locality:
Correlation: upper calcareous member
Lithology: calcareous sedimentary rock
Fossils:
Depositional environment:
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities:

Rimrock Mountain Group of Elston and others (1979) (Elston and others, 1979)
Age:
Occurrence/thickness: Pyramid Mountains (post-Muir caldera); Cookes Range
Type locality:
Correlation:

Lithology:
Fossils:
Depositional environment: post-caldera ash-flow tuffs and basaltic flows
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities:

Rincon Valley Formation (Santa Fe Group) (Seager and Clemons, 1975; Walker, 1986)
Age:
Occurrence/thickness: Cedar Hills; Good Sight Mountains/Uvas Valley; Rincon Hills; Rough and Ready Hills; San Diego Mountain–Tonuco Uplift; Sierra de las Uvas; Cookes Range
Type locality:
Correlation:
Lithology:
Fossils:
Depositional environment: Terrestrial deposits related to Rio Grande Rift (pediment–slope and fanglomerate deposits)
Stratigraphic relations to underlying rocks or predecessor(s): unconformable on Palm Park, Bell Top and Uvas Andesite in Good Sight–Cedar Hills area.
Stratigraphic relations to overlying rocks or successor(s):
Commodities: Rincon District: Gypsiferous clay deposits.

Ringbone Formation (Bisbee Group)(Lasky, 1938; Hayes, 1970; Zeller, 1970)
Age: Late Cretaceous
Occurrence/thickness: Brockman Hills (in subsurface); Klondike Hills (questioned occurrence); Little Hatchet Mountains (up to 2,288 m thick); Cookes Range
Type locality: None. Named for Ringbone Ranch of Little Hatchet Mountains, (Lasky, 1938)
Correlation:
Lithology:
Fossils:
Depositional environment:
Stratigraphic relations to underlying rocks or predecessor(s): overlies Mojado Formation
Stratigraphic relations to overlying rocks or successor(s):
Commodities:

Rubio Peak Formation (Hernon and others, 1953; Elston, 1953 (unpublished manuscript); Jicha,1954, Dane and others, 1961; Hernon and others, 1964; Clemons, 1979, 1982a, 1984; Jones and others, 1970;)
Age: Tertiary, Eocene and Oligocene (Strangway and others, 1976; Clemons, 1982)
Occurrence/thickness: Black Range/Mimbres Mountains; Cookes Range (latite-andesite units are 763 m thick); Florida Mountains (480 m thick); Little Florida Mountains; East Potrillo Mountains; Good Sight Mountains/Uvas Valley; Mogollon Mountains; Pinos Altos/Silver City Ranges
Type locality: None (Hernon and others, 1953). Named for a prominent butte at secs 9, 10, 15, 16, T. 19 S., R. 10 W., Dwyer quadrangle, Grant County
Correlation/subdivisions: informal Starvation Draw member at base mapped in the Cookes Range and the northern Florida Mountains (Clemons, 1982a; Clemons and Brown, 1983). The Starvation Draw Member in the Cookes Range is probably correlative to the Lobo

Formation in the Florida Mountains. Clemons, 1984, recommends discontinuing the usage of Starvation Draw Member.
Lithology: volcaniclastic rocks (conglomerate, sandstone, breccia). The constituents of the unit in the Florida Mountains indicates deposition into a basin adjoining a volcanic source. These units in the Victorio Mountains have been mapped as lower Tertiary units (Kottlowski, 1960a) and as Paleocene or Late Cretaceous rocks (Thorman and Drewes, 1980).
Fossils:
Depositional environment: fluvial deposits; ash-flow deposits (lahars)
Stratigraphic relations to underlying rocks or predecessor(s): disconformable on Lobo Formation in the Florida Mountains; deposited on the Sarten Sandstone and Colorado Shale in the Cookes Range.
Stratigraphic relations to overlying rocks or successor(s): Unconformable with Tertiary volcanic, intrusive, and sedimentary rocks and Quaternary sedimentary units. In Good Sight Mountains, is unconformably overlain by the Uvas Andesite and Bell Top Formation, and by Kneeling Nun Tuff in the northern part of the range.
Commodities: Zeolites at Dwyer deposit

Sacaton Mountain rhyolite (Rhodes, 1976; Ratté and others, 1984)
Age:
Occurrence/thickness: Mogollon Mountains, Bursum caldera
Type locality: none.
Correlation:
Lithology: mostly rhyolite, but includes dacite
Fossils:
Depositional environment: pre-resurgent dome of the Bursum caldera
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities:

San Andres Formation (Needham and Bates, 1943; Harbour, 1970; Seager, 1981)
Age: Early Permian, Leonardian, and early Guadalupian
Occurrence/thickness: Organ-San Andres Mountains; Cookes Range
Type locality: None. Named for San Andres Mountains, Socorro and Dona Ana Cox. (Lee, 1909) Type section: sec. 29, T 12 S., R. 2 E., Sierra Co (Needham and Bates, 1943)
Correlation/subdivisions: Named as upper formation of Manzano Group (Lee, 1909). Divided into (ascending) Rio Bonito, Bonney Canyon, and Fourmile Draw Members (Kelley, 1971).
Lithology:
Fossils:
Depositional environment:
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities: May host barite-fluorite deposits, Potrillo Mountains district. Localized gypdum occurrences throughout the MImbres Resource Area.

Santa Fe Group (Hayner Ranch Formation, Rincon Valley Formation and Selden Basalt Member of Rincon Valley Formation) (Hayden, 1869; Kelley and Silver, 1952; Kottlowski, 1953; Budding and others, 1960; Hawley and others, 1969; Machette, 1978; Maxwell and Oakman, 1990; Talmage and Wootton, 1937; Elston, 1957; Givens, 1957; Osburn and Chapin, 1983; Lozinsky and Hawley, 1986)

Age: Tertiary; Oligocene, Miocene, Pliocene, Quaternary, Pleistocene
Occurrence/thickness: Carrizalillo Hills; Cedar Hills; Cookes Range (with other flows and volcanics, 458 m thick); Jornada del Muerto; Mesilla bolson; Mimbres Mountains, Potrillo Basalt ---Santo Tomas, Black Mountain basalt fields(about 702 m thick)--Kilbourne Hole, ; Hunt's Hole; Rincon Hills (at least 305 m deep in water wells); Rio Grande Valley; Robledo Mountains (as much as 171 m thick); San Diego Mt/Tonuco Uplift
Type locality: none. Occupies greater portion of Rio Grande valley, Santa Fe Co (Hayden 1869). Type locality/area inferred by later workers as only those deposits (identified by Hayden) in gulches cut by tributaries of the Rio Grande extending to 40 mi north of Santa Fe.
Correlation:
Lithology:
Fossils: fresh-water and land-dwelling types
Depositional environment: Fan deposits, pediment veneers, older slope deposits, fluvial deposits, younger slope deposits with caliche caps, terrace deposits
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities: Caliche (as much as 15 m thick near Rincon Hills), sand and gravel, clay, adobe materials. Gypsum beds in fine-grained units.

Sarten Sandstone (Darton, 1916; Kottlowski, 1963; Hook and others, 1983; Cobban, 1987; Moore and others, 1988)
Age: Early and Late Cretaceous, Albian and Cenomanian
Occurrence/thickness: Cookes Range (92 m thick); San Andres Mountains, north of the Bear Peak fold and thrust zone
Type locality: None (Darton, 1916). Source of name is Sarten Ridge (now Rattlesnake Ridge) in the Cookes Range north of Deming, Luna Co, where it is well–exposed.
Correlation:
Lithology:
Fossils:
Depositional environment:
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities:

Scherrer Formation Naco Group (Gilluly and others, 1954; Zeller, 1958, 1965; Drewes, 1971, 1975, 1991)
Age: Early Permian (Wolfcampian and Leonardian)
Occurrence/thickness: Animas; Big Hatchet (up to 210 m thick); Peloncillo Mountains (up to 15 m); Cookes Range
Type locality: On Scherrer Ridge and Concha Ridge, Gunnison Hills, Cochise Co. AZ in SW1/4 SW1/4 sec 28, T. 15 S., R. 23 E., (Gilluly and others, 1954)
Correlation:
Lithology: quartz sandstone in a white limestone matrix.
Fossils:
Depositional environment:
Stratigraphic relations to underlying rocks or predecessor(s): conformable
Stratigraphic relations to overlying rocks or successor(s): conformable with Concha Limestone
Commodities:

Schoolhouse Mountain formation (Finnell, 1987)
Age:
Occurrence/thickness: Big Burro; Cookes Range
Type locality:
Correlation:
Lithology:
Fossils:
Depositional environment:
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities: Cora Miller district, northern Big Burro Mountains

Shelley Peak Tuff (Ratté, 1981; Marvin and others, 1987; Lawrence, 1986)
Age: Tertiary, Oligocene; about 30 m.y. old
Occurrence/thickness: Mogollon Mountains; Cookes Range
Type locality: section: SE 1/4 sec 11 T. 13 S., R. 17 W., named for Shelley Peak, Catron Co (Ratté, 1981)
Correlation:
Lithology:
Fossils:
Depositional environment: volcanic; source probably in the Gila Cliff Dwellings caldera (Ratté and others, 1984)
Stratigraphic relations to underlying rocks or predecessor(s): coextensive and gradational with the Davis Canyon Tuff
Stratigraphic relations to overlying rocks or successor(s):
Commodities:

Sierrite Formation (first named as lower part, El Paso Group)(Kelley and Silver, 1952; Zeller, 1965; Maxwell and Oakman, 1990; Drewes, 1991a)
Age: Early Ordovician
Occurrence/thickness: San Diego Mt/Tonuco Uplift; Cookes Range
Type locality: Exposures on north side of Cable Canyon, sec. 10, T. 16 S., R. 4 W., Caballo Mountains, Sierra County (Kelley and Silver, 1952)
Correlation:
Lithology:
Fossils:
Depositional environment:
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities:

Simpson Group (named for village of Simpson, north of Pontotoc, Oklahoma)(Mahar, 1946; Ross and Tweto, 1980)
Age: middle Ordovician
Occurrence/thickness: Southern Oklahoma folded belt province, Kansas, southeast Colorado
Type locality: none
Correlation:
Lithology: clastic units

Fossils:
Depositional environment:
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities:

Skeleton Canyon tuff (McIntyre, 1988)
Age: Tertiary; younger than Geronimo Trial caldera
Occurrence/thickness: Peloncillo Mountains
Type locality:
Correlation:
Lithology:
Fossils:
Depositional environment: volcanic tuff which marks the initial collapse of the Clanton Draw caldera (McIntyre, 1988)
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities:

Skunk Ranch Conglomerate (Bisbee Group)(Lasky, 1938; Zeller, 1970; Hayes, 1970)
Age: Late Cretaceous
Occurrence/thickness: Little Hatchet Mountains
Type locality: None designated. Named for outcrops west and south of Skunk Ranch, Little Hatchet Mountains (Lasky, 1938)
Correlation:
Lithology:
Fossils:
Depositional environment:
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities:

Smeltertown Formation (Strain, 1976; Nodeland and Cornell, 1976)
Age: Early Cretaceous, Comanchean and late Albian
Occurrence/thickness: Cerro de Cristo Rey
Type locality: section: NW1/4 SW1/4 NW1/4 sec 15, T. 29 S., R. 4 E., for lower part (units 1 and 2) and SE 1/4 SE1/4 NE/4 sec 16, T. 29 S., R. 4 E., for upper part (units 3 and 4), Dona Ana Co; named for small community across Rio Grande east of Cerro de Cristo Rey (Strain, 1976)
Correlation:
Lithology:
Fossils: microfossils
Depositional environment:
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities:

Soledad Rhyolite (Dunham, 1935)

Age: Tertiary
Occurrence/thickness: Organ Mountains (Organ batholith); Cookes Range
Type locality: none. Mountains adjacent to Soledad Canyon, for which unit is probably named in the Organ Mountains, Dona Ana Co. (Dunham, 1935)
Correlation:
Lithology:
Fossils:
Depositional environment: Units of the Organ caldera complex; moat and ring–fracture deposits.
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities:

Steeple Rock, rhyolite (Marvin and others, 1988; Hedlund, 1990; Biggerstaff, 1974)
Age: about 34 m.y. (Marvin and others, 1988; Hedlund, 1990)
Occurrence/thickness: Steeple Rock area
Type locality:
Correlation:
Lithology: rhyolite
Fossils:
Depositional environment: volcanic flows and dome
Stratigraphic relations to underlying rocks or predecessor(s): unconformable with older sedimentary rocks and the andesite of Mt. Royal
Stratigraphic relations to overlying rocks or successor(s): unconformable with the Summit Mountains formation
Commodities:

Steins Mountain Quartz Latite Porphyry (tuff) (Gillerman, 1958; Richter and others, 1990)
Age: Tertiary
Occurrence: Peloncillo Mountains
Type locality: None designated. Forms Steins Mountain and hills to the east, Hidalgo County (Gillerman, 1958)
Correlation:
Lithologies:
Fossils:
Depositional environment: a light colored, densely welded ash-flow tuff; defined by as being related to the Steins caldera (Richter and others, 1990)
Stratigraphic relations to underlying rocks or precursors:
Stratigraphic relations to overlying rocks or successors:
Commodities:

Still Ridge Formation (Bisbee Group)(Gillerman, 1958; Hayes, 1970; Armstrong and others, 1978; Drewes, 1986)
Age: Early Cretaceous
Occurrence/thickness: central Peloncillo Mountains
Type locality: None designated. Named as a formation of the Bisbee Group (Gillerman, 1958)
Correlation:
Lithology:
Fossils:

Depositional environment:
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities:

Sugarloaf Peak quartz monzonite (Seager, 1981; Seager and McCurry, 1988)
Age: Tertiary
Occurrence/thickness: Organ Mountains (Organ batholith)
Type locality: none.
Correlation:
Lithology: quartz monzonite; may have undergone widespread sericitic alteration; pegmatite locally
Fossils:
Depositional environment: Intrusive unit of the Organ batholith complex
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities: disseminated and veined pyrite and silver-bearing pegmatite east of San Augustin Pass (see Organ Mountains district)

Sugarlump Tuff (Hernon and others, 1964; Pratt, 1967; Jones and others, 1970; Strangway and others, 1976)
Age: Tertiary, Oligocene
Occurrence/thickness: Pinos Altos/Silver City; Cookes Range
Type locality: None
Correlation:
Lithology:
Fossils:
Depositional environment:
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities: Weathering into unusual forms justifies the formation of the City of Rocks and Giant of the Mimbres State Parks. Zeolite, Bayard deposit and Dwyer deposit

*__Summit Mountains formation__ (McLemore, 1995)
Age:
Occurrence/thickness: Steeple Rock area
Type locality:
Correlation:
Lithology: andesite
Fossils:
Depositional environment: lava flows, breccias, and volcaniclastic sedimentary rocks and intrusive rocks
Stratigraphic relations to underlying rocks or predecessor(s): Unconformable on rhyodacite of Mt Royal and rhyolite of Steeple Rock
Stratigraphic relations to overlying rocks or successor(s): Unconformably overlain by Bloodgood Canyon Tuff, Davis Canyon Tuff, Dark Thunder Canyon Formation
Commodities:

Syrena Formation (Magdalena Group) (ref)
Age:
Occurrence/thickness: Pinos Altos (Twin Sisters caldera); Cookes Range
Type locality:
Correlation:
Lithology:
Fossils:
Depositional environment:
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities: Copper deposits at Continental mine. Skarn deposits (copper) in Piños Altos district and Santa Rita district.

Tadpole Ridge Quartz Latite (Elston, 1968; Marvin and others, 1987; Strangway and others, 1976)
Age: Tertiary
Occurrence/thickness: Pinos Altos/Silver City; Cookes Range
Type locality: None. Named for Tadpole Ridge, Pinos Altos Mountains, Grant Co (Elston, 1968)
Correlation:
Lithology:
Fossils:
Depositional environment:
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities:

Thunderbird Group (Thomann, 1981, 1991; Kottlowski and others, 1973)
Age: Precambrian, Middle Proterzoic
Occurrence/thickness: Franklin Mountains
Type locality: About 915 m northeast of Smugglers Pass in Fusselman Canyon (Thomann, 1981). Informally named for apparent shape on southwest side of South Franklin Mountain, southern Franklin Mountains, El Paso Co. TX (Kottlowski and others, 1973)
Correlation:
Lithology:
Fossils:
Depositional environment: conglomerrate, rhyolite lavas, and trachyte ignimbrites
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities:

Thurman Formation (Kelley and Silver, 1952)
Age: Tertiary, Oligocene and Miocene
Occurrence/thickness: Rincon Hills; Cookes Range
Type locality: Along road to Palm Park barite mine in secs 35, 36, T. 18 S., R. 3 W, Sierra Co. Named for Thurman Arroyo at south end of Caballo Mountains (Kelley and Silver, 1952)
Correlation:
Lithology:
Fossils:
Depositional environment:

Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities:

Tillie Hall Peak intrusive andesite (Ratté and Hedlund, 1981; Ratté and Brooks, 1983)
Age: 24 m.y. (Ratté and Hedlund, 1981)
Occurrence/unit thickness: Steeple Rock area, north of Tillie Hall Peak, about 10 km^2 in extent
Type locality:
Correlation:
Lithology:
Fossils:
Depositional environment:
Stratigraphic relations with underlying rocks or precursors: intrudes andesites of Pine Cienega Peak
Stratigraphic relations with overlying rocks or successors:
Commodities: Hosts the Telluritde mine

Turkey Knob latite (Thorman and Drewes, 1981)
Age: Oligocene
Occurrence/thickness: Cedar Mountains; Cookes Range
Type locality:
Correlation:
Lithology: latite
Fossils:
Depositional environment: volcanic flows; individual flows up to 20 m thick
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities:

Twin Peaks rhyolite; monzonite porphyry (Biggerstaff, 1974)
Age:
Occurrence/thickness: Black Hawk district, Burro Mountains
Type locality:
Correlation:
Lithology: rhyolite, monzonite porphyry
Fossils:
Depositional environment: dike or plug
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities: is associated with mineralized veins

U-Bar Formation (Zeller, 1962, 1965, 1970, 1976; Hayes, 1970)
Age: Early Cretaceous
Occurrence/thickness: Alamo-Hueco and Dog; Cookes Range; Animas Mountains; Big Hatchet Mountains (incomplete section); Little Hatchet Mountains (1,220 m); Peloncillo Mountains; Pyramid Mountains; Sierra Rica
Type locality: section: Composite type section with lower part in NE1/4 sec 10, T. 32 S., R. 15 W.; middle part in NW1/4 sec 32, T. 31 S., R. 15 W., and upper part in NE1/4 sec 31, T.

31 S., R. 15 W., Hidalgo Co (Zeller, 1965) Named for U-Bar Ridge, Big Hatchet Mountains
Correlation:
Lithology: limestone, shale
Fossils: oysters, *Exogyra*, *Pecten*, pelecypods, gastropods, corals,ammonites, nautiloids, echinoids, foraminifera, algae, petrified wood
Depositional environment: marine; reefs as thick as 150 m, and associated deposits
Stratigraphic relations to underlying rocks or predecessor(s): conformable on Hell-to Finish Formation
Stratigraphic relations to overlying rocks or successor(s): Mojado Formation
Commodities: impure gypsum (6 m and 15 m thick); slightly petroliferous in some sections in the Big Hatchet Mountains. Fluorspar deposits at Winkler Antiline, Gillespie district, Animas Mountains, occur as scattered pods and breccia cement in irregular fluorite-jasperoid replacement mantos. Oxidized skarn and carbonate-hosted lead-zinc deposits with associated copper sulfides occur where the Cretaceous U-Bar Formation limestone is in contact with quartz monzonite (Apache No. 2 Mining District).

Uhl Well, latite (Elston and others, 1983; Elston, 1994)
Age: Tertiary
Occurrence/thickness: Pyramid Mountains (Muir caldera); Cookes Range
Type locality:
Correlation:
Lithology: latite
Fossils:
Depositional environment: volcanic flows; moat and flank deposits along domes of Muir caldera
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities:

Upham Dolomite (Montoya Group)(Kelley and Silver, 1952; Zeller, 1965; Drewes, 1991)
Age: Middle Ordovician, Champlainian
Occurrence/thickness: Robledo Mountains (23 m thick); Victorio Mountains; Cookes Range; Big Hatchet Mountains
Type locality: Opposite the Sierrite Mine at head of Cable Canyon, NW1/4 sec 10, T. 16 S., R. 4 W., Caballo Mountains, Sierra Co (Kelley and Silver, 1952)
Correlation:
Lithology:
Fossils:
Depositional environment:
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities: Rincon District: Bat Cave Member, manganese deposits. Silver deposits in Lone Mountain district

Uvas Andesite (Kottlowski, 1953; Clemons, 1976)
Age: Tertiary, late Oligocene, early Miocene
Occurrence/thickness: Cookes Range; Cedar Hills; Good Sight Mountains/Uvas Valley; Rincon Hills; Rough and Ready Hills; Jornada del Muerto, San Diego Mt/Tonuco Uplift; Sierra de las Uvas;

Type locality: None (Kottlowski, 1953). First used as Uvas Basalt (Kottlowski, 1953).
Correlation: potentially correlative units in the Carrizalillo Hills
Lithology:
Fossils:
Depositional environment: vent(ash flow) deposits. May be the first unit to be directly related to the Rio Grande rift (Seager and Clemons, 1975)
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s): Rincon Valley Formation
Commodities: Cinder, volcanic rock

Virden Formation (Elston, 1960; Kottlowski, 1963; Morrison, 1965; Hedlund, 1990)
Age: Late Cretaceous (Late Cretaceous to Paleocene; Hedlund, 1990)
Occurrence/thickness: West Potrillo Mountains; Cookes Range
Type locality: Sec. 16, T. 18 S., R. 20 W., Hidalgo County (Elston, 1960)
Correlation:
Lithology: sandstone, conglomerate, siltstone
Fossils:
Depositional environment: nonmarine
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities:

Wamels Pond rhyolite (Peterson, 1976; Deal and others, 1978)
Age: Tertiary
Occurrence/thickness: Sierra Rica/Apache Hills
Type locality:
Correlation:
Lithology:
Fossils:
Depositional environment: volcanic rocks
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities:

West Potrillo Basalt (Bersch, 1977; Ortiz, 1979; Hoffer and Sheffield, 1981; Hoffer and Ortiz, 1981)
Age:
Occurrence/thickness: West Potrillo Mountains; Cookes Range
Type locality:
Correlation:
Lithology:
Fossils:
Depositional environment:
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities:

West Side lavas (Seager, 1981; McIntosh and others, 1992)

Age: Tertiary
Occurrence/thickness: Organ (Organ batholith); Cookes Range
Type locality:
Correlation:
Lithology:
Fossils:
Depositional environment: moat and ring–fracture deposits of Organ caldera complex
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities:

White Eagle Rhyolite (Elston, 1975)
Age: Tertiary
Occurrence/thickness: confined to the northern end of the Cookes Range
Type locality: None designated. Named for White Eagle mine, sec. 34, T. 19 S., R. 9 W., Grant County
Correlation:
Lithology: porphyritic rhyolite flows, sills, and dikes
Fossils:
Depositional environment:
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities:

Whitewater Creek Member (Cooney Tuff) (Ratté, 1981; Marvin and others, 1987; Strangway and others, 1976)
Age: Tertiary, Oligocene
Occurrence/thickness: Mogollon Mountains; Cookes Range
Type locality: section: SE1/4 sec. 6, T. 11 S., R. 19 W., Catron Co. (Ratté, 1981)
Correlation:
Lithology:
Fossils:
Depositional environment:
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities:

Willow Creek rhyodacite porphyry (Hedlund, 1990c)
Age:
Occurrence/unit thickness: Steeple Rock area
Type locality:
Correlation:
Lithology: rhyodacite
Fossils:
Depositional environment: volcanic flow
Stratigraphic relations with underlying rocks or precursors:
Stratigraphic relations with overlying rocks or successors:
Commodities:

Wood Canyon tuff (Reiter, 1980)
Age:
Occurrence/thickness: Alamo-Hueco and Dog; Cookes Range
Type locality:
Correlation:
Lithology:
Fossils:
Depositional environment:
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities:

Woodhaul Canyon tuff (Deal and others, 1978)
Age: 36.82+0.81 m.y. old (biotite, K-Ar; Deal and others, 1978); approximates the date of Muir caldera
Occurrence/thickness: Pyramid Mountains (Muir caldera); Cookes Range
Type locality:
Correlation:
Lithology: rhyolite; intensely argillized and pyritized in Pyramid Mountains
Fossils:
Depositional environment: volcanic ash flow
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities: hosts volcanic-epithermal vein deposits in the Silver Tree and Allen mines, Muir mining district, Pyramid Mountains

Yeso Formation (Lee, 1909; Needham and Bates, 1943; Bachman and Hayes, 1958; Kelley, 1971)
Age: Early Permian, Leonardian
Occurrence/thickness: northern San Andres (beyond Mimbres Resource Area boundaries); Cookes Range
Type locality: None. Named for Mesa del Yeso, 19 km northeast of Socorro, Socorro Co. (Lee, 1909) Section: secs 4,5 T. 2 S., R. 2 E., and sec. 33, T. 1 S., R. 2 E., Socorro Co. (Needham and Bates, 1943). Named as middle unit of Manzano Group (Lee, 1909)
Correlation:
Lithology: Yeso is Spanish for gypsum
Fossils:
Depositional environment:
Stratigraphic relations to underlying rocks or predecessor(s):
Stratigraphic relations to overlying rocks or successor(s):
Commodities: Gypsum in small deposits and occurrences

List of plates

Click on a plate number to view the plate.

Plate 1. Geologic map of the Mimbres Resource Area, New Mexico.

Plate 2. Map showing permissible and non-permissible mineral-resource tracts and favorable areas for the occurrence of porphyry copper and related deposit types in the Mimbres Resource Area, southwestern New Mexico

Plate 3. Map showing permissible and non-permissible mineral-resource tracts and favorable areas for the occurrence of carbonate-hosted deposit types in the Mimbres Resource Area, southwestern New Mexico

Plate 4. Map showing permissible and non-permissible mineral-resource tracts and favorable areas for the occurrence of metallic vein deposits in the Mimbres Resource Area, southwestern New Mexico

Plate 5. Map showing permissible and non-permissible mineral-resource tracts and favorable areas for the occurrence of epithermal deposit types in the Mimbres Resource Area, southwestern New Mexico

Plate 6. Map showing permissible and non-permissible mineral-resource tracts for the occurrence of volcanogenic massive sulfide deposits in the Mimbres Resource Area, southwestern New Mexico

Plate 7. Map showing permissible and non-permissible mineral-resource tracts and favorable areas for the occurrence of rhyolite-hosted tin deposits in the Mimbres Resource Area, southwestern New Mexico

Plate 8. Map showing permissible and non-permissible mineral-resource tracts and favorable areas for the occurrence of gold placer deposits in the Mimbres Resource Area, southwestern New Mexico

Plate 9. Map showing permissible and non-permissible mineral-resource tracts and favorable areas for the occurrence of sediment-hosted copper deposits in the Mimbres Resource Area, southwestern New Mexico

List of tables

Click on a table number to view the table.

Table 1-1. Land status, Mimbres Resource Area (after Bureau of Land Management, 1994).

Table 1-2. Commodities, years of production, and deposit types from mining districts within the Mimbres Resource Area

Table 1-3. Base- and precious-metal production in the Mimbres Resource Area.

Table 1-4. Production of placer gold (oz) in the Mimbres Resource Area

Table 1-5. Known barite and fluorite production from mines in the Mimbres Resource Area.

Table 1-6. Uranium production from mines in the Mimbres Resource Area

Table 1-7. Production of other commodities from mines in the Mimbres Resource Area.

Table 1-8. Tungsten production from the Mimbres Resource Area.

Table 1-9. Manganese production from the Mimbres Resource Area, 1883 through 1958.

Table 1-10. Selected active, inactive, and dismantled mills in the Mimbres Resource Area.

Table 2-1. Types of mineral deposits that occur or may occur in the Mimbres Resource Area.

Table 2-2. Grades and tonnages of types of porphyry copper deposits.

Table 3-1. Specifications of aeromagnetic surveys used to compile the aeromagnetic anomaly data of the Mimbres Resource Area.

Table 3-2. Drill holes, total depths, and map symbols for drill holes near seismic lines listed by county.

Table 3-3. Geologic units and corresponding map symbols used in drill hole logs from wells drilled near seismic refraction lines in southwest New Mexico.

Table 5-1.1. Metals production from Grant County, New Mexico from 1869 to 1982.

Table 5-1.2. Commodities from mines and prospects in the Alum Mountain mining district.

Table 5-1.3. Commodities from mines and prospects of the Caprock mining district.

Table 5-1.4. Commodities from mines and prospects in the Ricolite mining district.

Table 5-1.5. Metallic mineral production from the Black Hawk mining district.

Table 5-1.6. Commodities from mines and prospects in the Black Hawk mining district.

Table 5-1.7. Commodities from mines and prospects in the Bound Ranch mining district.

Table 5-1.8. Metallic mineral production from Burro Mountains (Tyrone) mining district.

Table 5-1.9. Commodities from mines and prospects in the Burro Mountains mining district.

Table 5-1-10. Copper production from the Tyrone mine.

Table 5-1-11. Commodities from mines and prospects of the Malone mining district.

Table 5-1-12. Metallic mineral production from the Telegraph mining district.

Table 5-1-13. Commodities from mines and prospects in the Telegraph mining district.

Table 5-1-14. Chemical analyses of samples from Wild Horse Mesa area, Telegraph district.

Table 5-1-15. Metallic mineral production from the White Signal mining district.

Table 5-1-16. Commodities from mines and prospects in the Northern Cookes Range mining

district.
Table 5-1-17. Metallic mineral prooduction from the Gold Hill mining district.
Table 5-1-18. Commodities from mines and prospects of the Gold Hill mining district.
Table 5-1-19. Metallic mineral production from the Carpenter mining district.
Table 5-1-20. Metallic mineral production from individual mines in the Carpenter mining district.
Table 5-1-21. Commodities from mines and prospects in the Carpenter mining district.
Table 5-1-22. Metallic mineral production from the Eureka mining district.
Table 5-1-23. Commodities from mines and prospects in the Eureka mining district.
Table 5-1-24. Commodities from mines and prospects in the Wilcox mining district.
Table 5-1-25. Commodities from mines and prospects in the Bayard mining district.
Table 5-1-26. Chemical analyses of samples from the Manhattan and Peerless claims.
Table 5-1-27. Metallic mineral production from the Chloride Flat mining district.
Table 5-1-28. Commodities from mines and prospects of the Chloride Flat mining district.
Table 5-1-29. Commodities from mines and prospects in the Copper Flat mining district.
Table 5-1-30. Commodities from mines and prospects in the Fierro-Hanover mining district.
Table 5-1-31. Metallic mineral production from the Fleming mining district.
Table 5-1-32. Commodities from mines and prospects in the Fleming mining district.
Table 5-1-33. Commodities from mines and prospects in the Georgetown mining district.
Table 5-1-34. Commodities from mines and prospects in the Gila Fluorspar mining district.
Table 5-1-35. Metallic mineral production from the Lone Mountain mining district.
Table 5-1.36. Commodities from mines and prospects in the Lone Mountain mining district.
Table 5-1.37. Metallic mineral production from the Piños Altos mining district.
Table 5-1.38. Commodities from mines and prospects in the Piños Altos mining district.
Table 5-1.39. Metallic mineral production from the Steeple Rock mining district.
Table 5-1.40. Commodities from mines and prospects in the Steeple Rock mining district..
Table 5-2.1. Metallic mineral production from Hidalgo County, 1920-1957.
Table 5-2.2. Commodities from mines and prospects in the Antelope Wells-Dog Mountains mining district.
Table 5-2.3. Metallic mineral production from the Gillespie mining district.
Table 5-2.4. Commodities from mines and prospects in the Gillespie mining district.
Table 5-2.5. Commodities from mines and prospects in the Rincon mining district.
Table 5-2.6. Commodities from mines and prospects in the Big Hatchet Mountains mining district..
Table 5-2.7. Metallic mineral production from the Sylvanite mining district.
Table 5-2.8. Commodities from mines and prospects in the Sylvanite mining district.
Table 5-2.9. Chemical analyses of samples from the Sylvanite mining district.

Table 5-2-10. Metallic mineral production from the Granite Gap mining district.
Table 5-2.11. Commodities from mines and prospects in the Granite Gap mining district.
Table 5-2.12. Commodities from mines and prospects in the Kimball mining district..
Table 5-2.13. Commodities from mines and prospects in the McGhee Peak mining district.
Table 5-2.14. Metallic mineral production from the Lordsburg mining district. mining district.
Table 5-2.15. Commodities from mines and prospects in the Lordsburg mining district.
Table 5-2.16. Commodities from mines and prospects in the Muir mining district.
Table 5-2.17. Metallic mineral production from the Apache No. 2 mining district.
Table 5-2.18. Commodities from mines and prospects in the Apache No. 2 mining district.
Table 5-2.19. Metallic mineral production from the Fremont mining district.
Table 5-2.20. Commodities from mines and prospects in the Fremont mining district.
Table 5-3.1. Metallic mineral production from Luna County.
Table 5-3.2. Commodities from mines and prospects in the Carrizalillo mining district.
Table 5-3.3. Metallic mineral production from the Cookes Peak mining district.
Table 5-3.4. Commodities from mines and prospects in the Cookes Peak mining district.
Table 5-3.5. Metallic mineral production from the individual mines in the Cookes Peak mining district.
Table 5-3.6. Commodities from mines and prospects in the Old Hadley mining district.
Table 5-3.7. Metallic and industrial mineral production from the Fluorite Ridge mining district.
Table 5-3.8. Metallic mineral production from the Florida Mountains mining district.
Table 5-3.9. Commodities from mines and prospects in the Florida Mountains mining district.
Table 5-3.10. Commodities from mines and prospects in the Little Florida Mountains mining district.
Table 5-3.11. Commodities from mines and prospects in the Camel Mountain-Eagle Nest mining district.
Table 5-3.12. Metallic mineral production from the Tres Hermanas mining district.
Table 5-3.13. Commodities from mines and prospects in the Tres Hermanas mining district.
Table 5-3.14. Reported metal production from the Victorio district.
Table 5-3.15. Commodities from mines and prospects in the Victorio mining district.
Table 5-4.1. Mines and prospects in the Doña Ana Mountains district.
Table 5-4.2. Chemical analyses of samples from the Doña Ana Mountains district.
Table 5-4.3. Commodities from mines and prospects in the Portrillo Mountains.
Table 5-4.4. Commodities from mines and prospects in the Northern Franklin Mountains mining district.
Table 5-4.5. Commodities from mines and prospects in the Bear Canyon district.
Table 5-4.6. Commodities from mines and prospects in the Black Mountain mining district.

Table 5-4.7. Metal production from the Organ Mountains district.
Table 5-4.8. Mines and prospects in the Organ Mountains mining district.
Table 5-4.9. Chemical analyses of samples from the Organ Mountains district.
Table 5-4.10. Commodities from mines and prospects in the San Andrecity-Hembrillo mining district.
Table 5-4.11. Chemical analyses of samples from the Green Crawford, Hospital Canyon, and Hembrillo Canyon mines.
Table 5-4.12. Commodities and production from mines and prospects in the Rincon district.
Table 5-4.13. Commodities from mines and prospects in the Tonoco mining district.
Table 6-1. Mineral deposit types used int he quantitative assessment of the Mimbres Resource Area. With the types of commodities modeled and references.
Table 6-2. Estimates of undiscovered porphyry deposit types in the Mimbres Resource Area.
Table 6-3. Expected mean tonnages of metals in undiscovered porphyry deposits in favorable areas of the Mimbres Resource Area.
Table 6-4. Estimates of undiscovered carbonate-hosted deposit types in the Mimbres Resource Area.
Table 6-5. Estimates of undiscovered carbonate-hosted deposit types in the Mimbres Resource Area.
Table 6-6. Expected mean tonnages of metals in undiscovered carbonate-hosted deposits in favorable areas of the Mimbres Resource Area.
Table 6-7. Expected mean numbers of undiscovered carbonate-hosted deposits in favorable areas of the Mimbres Resource Area.
Table 6-8. Estimates of undiscovered metallic vein deposit types in the Mimbres Resource Area.
Table 6-9. Expected mean numbers of undiscovered metallic vein deposits in favorable areas of the Mimbres Resource Area.
Table 6-10. Estimates of undiscovered epithermal deposits in the Mimbres Resource Area.
Table 6-11. Expected mean tonnages of metals in undiscovered epithermal deposits in favorable areas of the Mimbres Resource Area.
Table 6-12. Estimates of undiscovered volcanogenic massive sulfide deposits in the Mimbres Resource Area.
Table 6-13. Expected mean tonnages of metals in undiscovered volcanogenic massive sulfide deposits in favorable areas of the Mimbres Resource Area.
Table 6-14. Estimates of undiscovered gold placers, rhyolite-hosted tin, and sediment-hosted copper deposits in the Mimbres Resource Area.
Table 6-15. Expected mean tonnage of metals in undiscovered gold placers, rhyolite-hosted tin,

and sediment-hosted copper deposits in the Mimbres Resource Area.

Table 6-16. Gross in-place values of commodities in undiscovered deposits in the Mimbres Resource Area.

Table 6-17. Gross in-place values of undiscovered deposits in the Mimbres Resource Area, ranked by favorable area.

Table 6-18. Undiscovered deposit types that may be included in the aggregated areas and the criteria used to delineate favorable areas.

Table 6-19. Gross in-place values of undiscovered deposits in the Mimbres Resource Area ranked by aggregated area.

Table 6-20. Estimated 1993 U.S. Apparent consumption, net import reliance, estimated undiscovered resources, and E/C index for selected nonfuel mineral commodities that occur in the Mimbre Resource Area.

Table 6-21. Estimated resources reported for undiscovered deposits in the Mimbres Resource Area ranked by aggregated area.

Table 6-22. Estimated past production and identified resources of selected metals compared to the amounts of metals in undiscovered mineral deposits of selected types in the Mimbres Resource Area.

Table 6-23. Estimated past production and identified resources of selected metals compared to the amounts of metals in undiscovered mineral deposits of selected types in the Mimbres Resource Area.

Table 7-1. Listing of the relative availability and quality of potential sources of sand and gravel in the Mimbres Resource Area.

Table 7-2. Areas and volumes of sand and gravel resources by deposit type and quality.

Table 7-3. Occurrences of alunite and alum in the Mimbres Resource Area.

Table 7-4. Barite and fluorite districts and occurrences int he Mimbres Resource Area.

Table 7-5. Selected scoria deposits in Doña Ana and Luna Counties.

Table 7-6. Formulas of zeolites that commonly occur in sedimentary rocks.

Table 7-7. Chemical analyses of nearly monomieralic chabazite- and clinoptilolite-rich marker tuff from the Gila Conglomerate near Buckhorn, Grant County.

List of map figures, sections, diagrams

(Click on entry to display)

Index map of the Mimbres Resource Area, New Mexico.

Federal and State lands, Mimbres Resource Area, New Mexico.

Correlation chart of geologic units, Mimbres Resource Area, New Mexico.

Pre-Laramide tectonic features, Mimbres Resource Area.

Laramide tectonic features, Mimbres Resource Area.

Post-Laramide tectonic features, Mimbres Resource Area.

Basin-and-Range tectonic features, Mimbres Resource Area.

Structure map of the area northwest of Las Cruces, including the Black Range uplift, Cobre uplift, Caballo uplift, Good Sight uplift, Cedar Hills uplift, and Sierra de las Uvas dome.

Mining districts in the Mimbres Resource Area, southwest New Mexico.

Mill locations, past and present, in the Mimbres Resource Area.

Digital terrain map of the Mimbres Resource Area.

Complete Bouguer gravity anomaly map, Mimbres Resource Area.

Composite aeromagnetic map, Mimbres Resource Area.

Maps showing seismic refraction and composite deep crustal velocity sections in the southern Mimbres Resource Area.

Comparison of depths to lithologic contacts from seismic velocity sections and lithologic logs of drill holes.

Correlation of seismic velocity and lithology in southwestern New Mexico.

Map of seismic refraction shotpoints with complete Bouguer gravity anomaly contours and drill-hole locations.

Velocity section 1.

Velocity section 2.

Velocity section 3.

Velocity section 4.

Velocity section 5.

Velocity section 7.

Summary of geophysically inferred subsurface features.

Potassium aeroradioactivity map of the Mimbres Resource Area.

Uranium aeroradioactivity map of the Mimbres Resource Area.

Thorium aeroradioactivity map of the Mimbres Resource Area.

Uranium:Potassium aeroradioactivity map of the Mimbres Resource Area.

Uranium:Thorium aeroradioactivity map of the Mimbres Resource Area.

Potassium:Thorium aeroradioactivity map of the Mimbres Resource Area.

Generalized geology and NW-SE cross section through the Big Burro Mountains in the vicinity of Burro Peak and Tyrone stock.

Generalized geology of Gold Hill block.

Generalized geology of the Knight Peak graben area.

Structural setting near Santa Rita and Chino Mine.

Generalized geology and locations of mines in the Big Hatchet Mountains mining district, Hidalgo County.

Geology of the Brockman Hills.

Diagrammatic cross section through the Carrizalillo Hills.

Generalized geologic map of the northern Cookes Range.

Cross section through Mahoney Ridge and Gym Peak areas, southern Florida Mountains.

Generalized structure of the Good Sight Mountains and Sierra de las Uvas area.

Generalized geology, showing faults, inferred faults, and stratigraphic column of the Granite Hill area, southeastern Luna County.

Generalized geology and structural map and south-north cross section A-A' of the Klondike Hills, Luna County.

Generalized geologic map of the Victorio Mountains and cross sections A-A' and B-B’.

West-southwest to east-northeast cross section through Bishop Cap.

Cerro de Cristo Rey.

Doña Ana caldera.

Generalized geology of the East Potrillo Mountains and cross sections A-A'.

West-east cross section through the Rio Grande Valley near Interstate 70 showing the Jornada del Muerto, La Mesa, and Mesilla Valley surfaces.

North-south diagrammatic sections showing thickness variation of pre-Permian units above Precambrian basement, and Permian and post-Permian units.

Feldspathoidal basalt lava fields and related rocks, structural features, and test wells, Doña Ana County and adjacent parts of Luna County.

Profile of Aden crater.

Diagrammatic profile and cross-section of the Rio Grande Valley and piedmont slope east of Las Cruces.

Generalized geology of the Robledo Mountains.

East-west cross-section through the southern part of the Rough and Ready Hills, Doña Ana County.

Geologic map and cross sections, Tortugas Mountain, Doña Ana County.

Malpais maar, southern Doña Ana County.

Mines and prospects in the Alum Mountain mining district.
Locations of mines and prospects in the Caprock Mountain mining district, Grant County.
Mines and prospects in the Ricolite mining district, Grant County.
Mines and prospects in the Black Hawk mining district, Grant County.
Mines and prospects in the Cora Miller mining district, Grant County.
Mines and prospects in the Carpenter mining district, Grant County.
Mines and prospects in the Wilcox mining district, Grant and Catron Counties.
Diagrammatic sketch showing mineralization patterns in Laramide skarn deposits in southern New Mexico.
Locations of mines and prospects in the Fleming mining district, Grant County.
Mines at Georgetown near the turn of the century, Georgetown district.
Locations of mines and prospects in the Steeple Rock mining district, Grant County.
Map of the mines and prospects in the Gillespie mining district, Hidalgo County.
Locations of mines and prospects in the Rincon mining district.
Map of the mines and prospects in the Granite Gap mining districts, Hidalgo County.
Mines and prospects in the McGhee Peak mining district, Hidalgo County.
Map of the Silver Tip mining district, Hidalgo County.
Mines and prospects in the Lordsburg mining district, Hidalgo County.
Apache No. 2 mining district, Hidalgo County.
Mines, prospects, and assay values, Carrizalillo mining district.
Mines, prospects, and assay values, Carrizalillo Hills mining district.
Mines and prospects in the Camel Mountain-Eagle Nest district.
Mines and prospects in the Tres Hermanas mining district.
Mines and prospects in the Victorio mining district, Luna County.
Mines and prospects in the Potrillo Mountains, Doña Ana County.
Map of Copiapo jarosite mine, showing underground workings.
Mines and prospects in the Bear Canyon district, Doña Ana County.
District zoning in the Organ Mountains, Doña Ana County.
Simplified geologic sketch and plan map of the Green Crawford mines, Doña Ana County.
Mines and prospects in the Rincon district, Doña Ana County.
Diagram showing how the flow of information from field studies is applied to selection of deposit model and delineation of tracts on the mineral resource map.
Diagram showing how quantitative mineral resource assessment is derived from the mineral resource map, estimation of the number of undiscovered deposits, and worldwide grade and tonnage data.

Estimated tonnages of mineral deposit types in the Mimbres Resource Area ranked by the median size.
Probability estimates of expected tonnages of metals and mineralized material in porphyry copper-molybdenum and porphyry molybdenum, low fluorine deposits.
Probability estimates of expected tonnages of metals and mineralized material in undiscovered carbonate-hosted deposits.
Probability estimates of expected tonnages of metals and mineralized material in undiscovered metallic vein deposits. (A) Polymetallic vein (B) Au-Ag-Te veins
Probability estimates of expected tonnages of metals and mineralized material in undiscovered epithermal deposits.
Probability estimates of expected tonnages of metals and mineralized material in undiscovered volcanogenic massive sulfide deposits.
Probability estimates of expected tonnages of metals and mineralized material in undiscovered rhyolite-hosted tin deposits.
Probability estimates of expected tonnages of metals and mineralized material in undiscovered gold placer deposits.
Probability estimates of expected tonnages of metals and mineralized material in undiscovered sediment-hosted copper deposits.
Probability estimates of expected total tonnages of metals and mineralized material in undiscovered mineral deposits in the Mimbres Resource Area.
Flow diagram showing process to conduct asessment of crushed stone resources.
Flow diagram showing process to conduct assessment of sand and gravel resources.
Availability and relative quality of potential bedrock sources of crushed stone in the Mimbres Resource Area.
Availability and relative quality of potential sources of sand and gravel in the Mimbres Resource Area.
Minimum thickness in meters of sand and gravel deposits in alluvial fans.
Minimum thickness in meters of sand and gravel deposit in pits and quarries found in terraces along the Rio Grande Valley.
Gypsum resources in the Mimbres Resource Area.
Known perlite occurrences in the Mimbres Resource Area.
Scoria localities, Mimbres Resource Area.
Mines in the Mimbres Resource Area from which pumice production has been recorded.
Zeolite localities in Tertiary volcaniclastic rocks, Mimbres Resource Area.
Geothermal occurrences in the Mimbres Resource Area.
Uranium occurrences in the Mimbres Resource Area.